# FINAL REPORT

## Regulating Services as Measures of Ecological Resilience on DoD Lands

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**14. ABSTRACT**
Knowledge of the capacity and flow of ecosystem services can help DoD land managers make decisions that enhance cost-effectiveness, minimize environmental damage, and maximize resources available for military missions. We demonstrated a methodology to quantify and map selected regulating services (RS), which helps land managers envision tradeoffs. Our objectives were to 1) estimate current capacity of and demand for selected RS within DoD lands, 2) examine the effects of future DoD land management and climate changes on the capacity and flow of these RS, and 3) project how land-use and climate changes in nearby lands affect future demand for RS. Our approach incorporates widely accepted models and equations, remote sensing, GIS analysis, and stakeholder involvement. Required data include land cover/use, soil type, precipitation, and air temperature. We integrated data into the a) Surface Curve Number Method and b) Revised Universal Soil Loss Equation to estimate capacity of sediment, nitrogen (N) and surface-water regulation. Capacities and flows of RS vary greatly across landscapes and are likely to vary as climate changes or development occurs. Analyses of RS capacity and flow can help managers and planners prioritize actions in the context of best management practices and compatible use buffers. Staff surveys indicated that our approach was informative and easy to use. Implementation may be most limited by on-installation personnel time.

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Regulating service, service capacity, service flow, service demand, sediment regulation, nitrogen regulation, surface water regulation, spatial analysis

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**Acronyms:**

**AC – ambient condition**
**ACIL - annual contaminant input load**
**ACUB - Army Compatible Use Buffer**
**ANG-MTC - Army National Guard Maneuver Training Center**
**CRA - Critical riparian area**
**CWA – Clean Water Act**
**DEM – Digital Elevation Model**
**DoD – (United States) Department of Defense**
**EP - Environmental Partnerships**
**ES – ecosystem service**

**ESA- Endangered Species Act**
**ESRI – Economic and Social Research Institute**
**ESTCP – Environmental Security Technology Certification Program**
**EUG - End-User-Guide**
**FPWQ - Fort Pickett water quality**
**GIS – geographic information system**
**HU – Hydrologic unit**
**INRMP - Integrated Natural Resources Management Plan**
**LULC – Land use – land cover**
**LS - Slope length and steepness**
**MACL - measured annual contaminant load**
**MCAS – Marine Corp Air Station**
**N - Nitrogen**
**NASS - National Agricultural Statistics Service (USDA)**
**NC – North Carolina**
**NCDWQ – North Carolina Division of Water Quality**
**NEPA – National Environmental Policy Act**
**NLCD – National Land Cover Data**
**NRCS – Natural Resource Conservation Service**
**PRISM - Parameter-elevation Regressions on Independent Slopes Model**
**RAM - rapid access memory**
**RS – regulating (ecosystem) service**
**RUSLE - Revised Universal Soil Loss Equation**
**SPARROW - Spatially Referenced Regressions On Watershed attributes**
**SSURGO - Soil Survey Geographic Database (USDA-NRCS)**
**SWAT – Soil and Water Assessment Tool**
**SWY – Surface water yield**
**TER-S - threatened, endangered, and at-risk species**
**TMDL – total maximum daily load**
**TNC – The Nature Conservancy**
**TSS – Total suspended solids**
**US – United States**
**USACE – United States Army Corps of Engineers**
**USDA – United States Department of Agriculture**
**USEPA – United States Environmental Protection Agency**
**USGS – United States Geological Survey**
**VA - Virginia**
**VADEQ – Virginia Department of Environmental Quality**
**VAFM-E – Virginia Facilities Management – Environmental Division**
**WQ – Water quality**

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**Executive Summary**

## OBJECTIVES OF THE DEMONSTRATION

The project's overall objective was to provide the Department of Defense (DoD) with clearer insight into the current and future provision of freshwater ecosystem services germane to many environmental concerns faced by the DoD, including threatened, endangered, and at-risk species (TER-S), water quality compliance, and urban encroachment. The ecological resilience provided by regulating and supporting ecosystem services (RS) is important when planning land uses, whether for environmental stewardship or military training. Spatially explicit knowledge of RS capacity and flow can help DoD land managers make planning decisions that enhance cost-effectiveness, minimize environmental damage, and maximize the resources available for their military mission. Land-use choices by the DoD are made in the context of dynamic demographic, land-use, and climatic conditions on adjacent lands, which ultimately control RS capacity and flow. These dynamics can be depicted in future scenarios that enable land managers to envision tradeoffs and plan more effectively for environmental conflicts. Specific technical objectives were to (1) estimate current capacity of and demand for (i.e., ecological pressure on) selected RS within DoD lands, (2) examine the effects of future DoD land management (i.e., planned military and environmental operations) and climate changes on the capacity and flow of these RS, and (3) project how land-use and climate changes in nearby lands might affect future demand for RS within DoD lands.

## METHODOLOGY DESCRIPTION

The analytical framework that was demonstrated combines quantitative and spatial modeling to evaluate RS on and near DoD lands. Ecosystem service terminology varies widely among authors. Throughout this demonstration, the adopted terminology is derived from the current scientific literature. The approach, described below, incorporates widely accepted hydrologic models and equations, remote sensing, geographic information systems analysis, as well as stakeholder involvement. Although geographic information systems (GISs) are commonly used to assess RS via simple land cover proxies, our approach enables us to separately estimate the capacity and flow of RS by incorporating multiple layers of information, thereby increasing the resolution and accuracy of our analysis as well as its applicability to specific management questions.

Technical objectives were translated into 12 performance objectives. The first four performance objectives sought to improve production function details and spatial resolution of the Geographical Information System (GIS)-based analyses of our focal RS (i.e., surface water regulation and sediment & nitrogen regulation). The next two performance objectives sought to demonstrate transferability of our frameworks for measuring capacity of, demand on, demand

for, and flow of RS. Performance objectives seven and eight sought to demonstrate how to rank ecological pressures on RS and measure flow of RS to beneficiaries. The next two performance objectives sought to demonstrate how to minimize propagation errors in geospatial data and enhance RS-based decision support systems. Performance objectives 11 and 12 sought to demonstrate the utility of our framework for integrating RS into installation planning decisions and improve projections of RS to be used in that planning.

Baseline data required for the RS framework include land cover, land use, soil type and hydrologic characteristics, precipitation and air temperature. These data are publicly available, however, site-specific data also were incorporated when the resolution was significantly better or when the data were more up-to-date. The preceding data were integrated into several hydrological equations, including the (1) Surface Curve Number Method for estimating surface runoff based on land cover, soil type, and precipitation patterns and (2) Revised Universal Soil Loss Equation, based on land cover, soil erodibility, slope, and management practices. These equations were used to estimate capacity of sediment, nitrogen (N), and surface water regulation. Nitrogen regulation capacity was assessed in two phases—leaching and riparian filtration, which together reduce the N loading into streams, rivers, and lakes. Nitrogen lost from surface water via infiltration was calculated using the New York Nitrogen Leaching Index. Nitrogen removed via filtration was calculated from published N-removal efficiencies associated with agricultural and riparian zone best management practices.

The innovative framework proposed here distinguishes RS capacity from RS flow by mapping the hydrologic flow of disservices and services from source to stream and beneficiaries, respectively. Ecological pressures (sometimes called disservices) were mapped using three methods (including field-collected data) and the results were compared to determine the most cost- and time-effective strategy for land use planning. The three methods were established to reflect three levels of time and computer processing investment. Because the demand for RS depends largely on the magnitude and location of ecological pressures (e.g., sediment, nitrogen, and excessive surface water), the flow paths of known pressures were mapped as well as potentially unknown pressures from training areas. Finally, this project demonstrated a method to quantify the magnitude of RS generated on military installations by comparing water quality monitoring data to modeled estimates of upstream soil loss and ranking the watersheds based on their ecological pressure and ambient condition.

The geospatial analysis associated with this project was initially conducted within the ArcGIS environment, first in Economic and Social Research Institute version 9.3 and later adapted for ArcMap version 10.2 to correspond to updated systems used on military installations. Presentations of results and scenario planning meetings were conducted several times at two military installations (Army National Guard Maneuver Training Center Fort Pickett and Marine

Corp Air Station Cherry Point) throughout the demonstration, and a field validation of land cover data was conducted on both installations.

## DEMONSTRATION RESULTS

This demonstration showed that many environmental issues (e.g., compliance with National Environmental Policy Act, Endangered Species Act, and Clean Water Act; suburban encroachment) facing military installations can be analyzed as tradeoffs among ecosystem services (ES). For example, this project's approach to ES analysis can inform planners regarding how dedicating a land parcel to training, housing, or stewardship will influence surface water quality or flooding. Capacities and flows of ES vary greatly across landscapes and are likely to vary as climate changes or development occurs. For example, climate change may increase N leaching if precipitation increases and off-installation development may impact on-installation water quality. The GIS maps developed via the approach herein are instructive in showing variation in ES capacities and flows. ES capacities often can be estimated via existing data but a need exists to validate data and recognize resolution limits; in some situations new kinds of data are needed. For example, adequate data on ambient water quality were sometimes lacking and some land cover data were out of date. Analyses of ES capacity and flow are useful to managers and planners by helping them identify and prioritize management targets. For example, flow-path analysis helps identify trouble spots to guide effective implementation of best management practices and ES analysis can inform prioritization of compatible use buffers. Responses to the end-of-project surveys of installation staff likely to use this framework and/or tools indicated that the demonstrated approach was informative, useful, and easy to use in the context of installation environmental compliance and land use planning. Because the analytical approach is new, much room for improvement remains. Refining the models and tools demonstrated herein will lead to better management choices and outcomes. The new tools that were developed are accessible to on-installation GIS analysts or hired consultants.

This demonstration included 12 performance objectives, ten quantitative and two qualitative, that were initially designed to evaluate the success of the demonstration. Success was achieved on performance objective 1-4, 11, and 12 and partial success on performance objectives 5-7, 9-10. Due to changes in the scope of the demonstration and data available during the demonstration, performance objective 8 was modified to better inform the impacts of regulating service capacity within installation boundaries and on lands in the corresponding encroachment buffer program. Limited success on performance objectives was largely attributed to the lack of on-the-ground water quality monitoring data that would be needed to quantify the actual flow of regulating services occurring (e.g., surface water retention).

## IMPLEMENTATION ISSUES

Few future issues, especially technological constraints, limit the implementation of the demonstrated framework for using regulating services to evaluate ecological resilience. The GIS tools that were developed can be used within the Arc GIS 10.2 environment and require no further licenses beyond those already owned. End products, along with an End-User Guide that will enable GIS analysts to conduct the same analyses described in this report as well as adapt and update the underlying models as needed (through Python scripting or in Model Builder). The tools demonstrated in this project were developed to facilitate assessment of baseline and future changes to the landscapes of specific installations and surrounding areas. With such assessments, however, comes the need for (1) accurate information that drives the specification of model parameters and (2) time for staff to conduct the analyses. On-installation personnel time was the most limited resource, followed by on-the-ground data from water quality monitoring; both limited the success of the demonstration and implications for future implementation. Implementation of the methodology herein may lead to re-assessments of the tradeoffs installations make in prioritizing their limited resources for environmental management. Even so, the work shows that implementing an RS-based assessment framework and methodology can provide insight into future land management on military installations, including decisions related to encroachment buffers, stewardship, and regulatory compliance.

# INTRODUCTION

## 1.1 BACKGROUND

Military installations must pursue their missions while also addressing environmental issues, including imperiled species conservation, water quality protection, and encroachment mitigation. Ecosystem services (ES) provide a new framework for understanding landscape-scale environmental issues and can clarify spatial patterns, tradeoffs, and synergies of interest to stakeholders, including the Department of Defense (DoD) (Millennium Ecosystem Assessment 2005). Delivery of ES is strongly influenced by land/water use and the distribution of people who value them. Thus, changes in land/water use in or near DoD lands may affect ES germane to the military mission. Understanding current sources and flows of ES and projecting shifts in their delivery (e.g., due to climate change) will help DoD land/water managers develop cost-effective strategies regarding many environmental issues  Despite the pressing need to understand ES delivery, there is no readily available methodology for incorporating knowledge of ES into DoD decision-making (The Nature Conservancy 2008). Ecosystem service terminology varies widely among authors. Throughout this demonstration, we have adopted terminology of Villamagna et al. (2013).

Regulating services (RS), the benefits derived from ecological processes that regulate valued ecological features (e.g., water purification), are of particular interest to DoD managers because they strongly influence ecosystem resilience (i.e., the ability to withstand perturbations without suffering degradation).  Several biophysical factors determine a landscape’s capacity to deliver a given RS. However, many human actions decrease the capacity of RS while increasing the demand for these services (Carpenter et al. 2006). Our analytical approach provides an objective method for measuring and mapping RS and identifying areas of high or low capacity (i.e., high or low ecological resilience). This information will help DoD managers connect planned activities with appropriate locations, thereby enhancing cost-effectiveness of installation operations. Furthermore, our framework is widely applicable and can provide a biophysical estimate of ES delivery from which more accurate economic valuations can be derived.

Land-use choices by military installations must be made in the context of regional community dynamics and land-use and climate changes on adjacent lands, which ultimately control RS capacity, demand, and flow. Scenario analysis is a powerful tool for bringing together stakeholders to consider their shared but uncertain future, including their sharing of ES. Such collaborative exercises can help DoD land managers plan more effectively for environmental conflicts. In this demonstration, we tested if an integrative approach to characterizing RS delivery, based on a suite of biophysical data layers, provides a better conceptualization and inventory of ES than prevailing approaches that simplistically rely on land cover proxies or ambient conditions. We separately estimated and mapped current capacity of and demand for

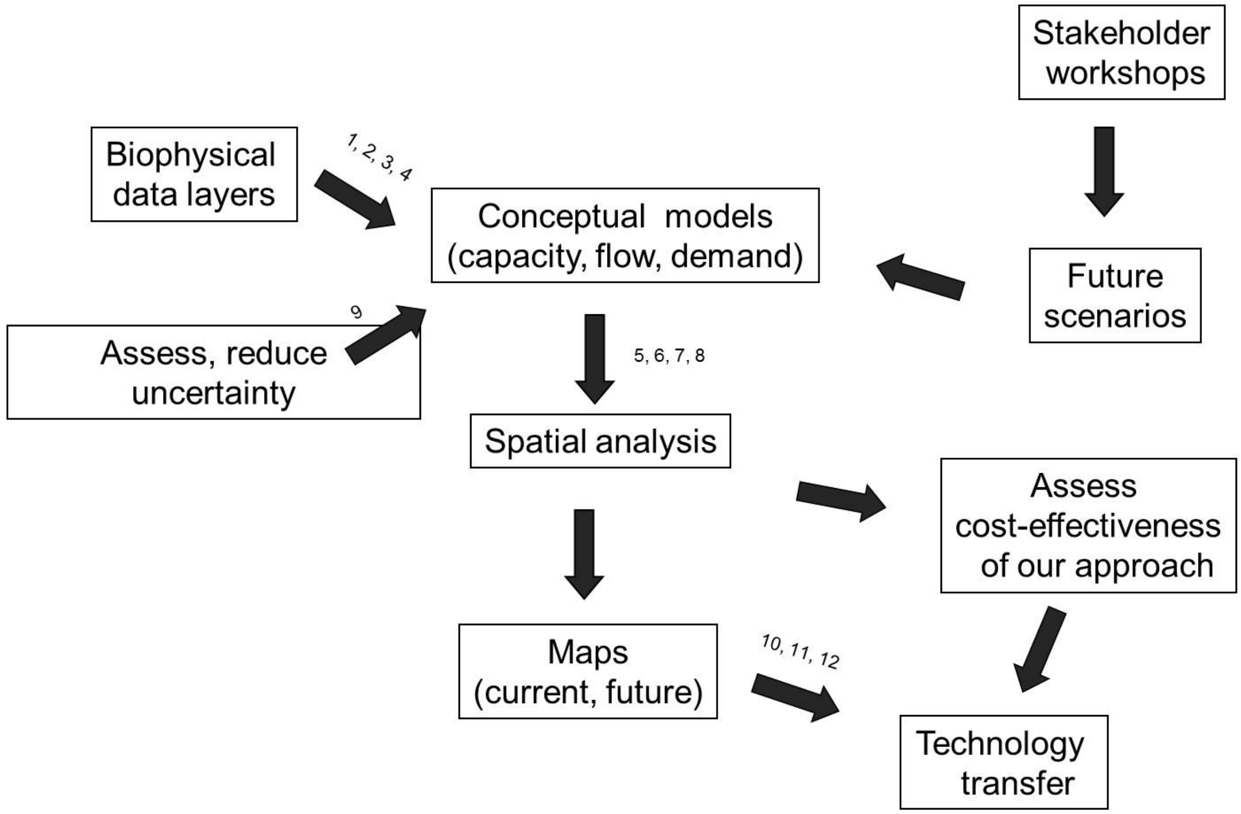
selected aquatic ES that can be used to estimate and map ES flow. We also estimated effects on RS flow induced by changes in climate or land/water use by recalculating RS capacity and demand under selected plausible scenarios germane to installation-specific issues. Such knowledge will enable planners to determine which areas are best suited for different land uses (e.g., military training, housing, or forest buffer) and which areas will be most affected by region-wide transformation due to land use or climate change.

## 1.2 OBJECTIVE OF THE DEMONSTRATION

Our overall objective was to provide the DoD with clearer insight into the current and future provision of freshwater ecosystem services germane to many environmental issues faced by the DoD, including threatened, endangered, and at-risk species (TER-S), water quality, and urban encroachment. The ecological resilience provided by RS is important when planning land uses, whether for environmental stewardship or military training. Spatially explicit knowledge of RS capacity and flow can help DoD land managers make planning decisions that enhance cost-effectiveness, minimize environmental damage, and maximize the resources available for their military mission. Our specific technical objectives are to 1) estimate current capacity of and demand for (i.e., ecological pressure on) selected RS within DoD lands, 2) examine the effects of future DoD land management (i.e., planned military and environmental operations) and climate changes on the capacity of these RS, and 3) project how land-use and climate changes in nearby lands might affect future demand for RS within DoD lands. Figure 1 depicts relations between performance objectives and demonstration tasks.

In this report, we address our objectives via analyses conducted at two military installations (Fort Pickett and Cherry Point), which face environmental issues similar to many others across the United States. Each installation offers distinctive opportunities to use analyses of RS in resolving planning and stewardship choices. The following sections summarize, in turn, our methodology, performance objectives, study sites, test design, actual performance, demonstration costs, and implementation issues.

**Figure 1: Flow diagram depicting the main demonstration components and associated performance objectives. Numbers near arrows refer to performance objectives.**




## 1.3 REGULATORY DRIVERS

To our knowledge, there are no existing or anticipated regulations or DoD directives that have articulated the need for this new methodology.

# 2.0 METHODOLOGY DESCRIPTION

## 2.1 METHODOLOGY OVERVIEW

The analytical framework demonstrated combines quantitative and spatial modeling to evaluate RS on and near DoD lands. The approach, described below, incorporates widely accepted hydrologic models, remote sensing and geographic information systems (GISs) analysis (ArcGIS version 10.0), and stakeholder involvement. While GIS is commonly used to assess RS via simple land cover proxies, our approach enables us to separately estimate the capacity and flow of RS by incorporating multiple layers of information, thereby increasing the resolution and accuracy of our analysis as well as its applicability to specific management questions.

Baseline data required for our RS framework include land cover, land use, soil type and hydrologic characteristics, precipitation and air temperature and, where necessary, species distributions. These data are publicly available, but we also incorporated additional site-specific data where the resolution was significantly better or when the data were more recent (e.g., Army National Guard Maneuver Training Center [ANG-MTC], Fort Pickett Natural Resource Geographic Database [Virginia Facilities Management – Environmental Division and Emrick 2008]). We integrated these data into several hydrological equations, including the a) Surface Curve Number Method (United States Department of Agriculture - Natural Resource Conservation Service [USDA-NRCS] 1972) for estimating surface runoff based on land cover (USDA-National Agricultural Statistics Service [NASS] 2009), soil type (USDA-NRCS 2006b), and precipitation patterns (USDA-NRCS 2006a) and b) Revised Universal Soil Loss Equation (USDA-NRCS 2003), based on land cover, soil erodibility, slope, and management practices. We used these equations to estimate capacities of sediment regulation and surface water regulation. Nitrogen-regulation capacity was treated as two linked processes – infiltration (or leaching) and filtration – that prevent nitrogen (N) from entering waterbodies. Nitrogen lost from surface water via infiltration was calculated from the New York Nitrogen Leaching Index (Czymmek et al. 2003). Nitrogen removed via filtration was calculated from published N-removal efficiencies associated with agricultural and riparian zone best management practices (BMPs). Data sources, resolution, and spatial extent are provided in Appendix B.

Our innovative framework distinguishes RS capacity from RS flow by incorporating estimates of the demand for RS. Demand for RS, which is socially derived, depends on the magnitude of inputs and the desired outcome or condition, as might be stated in state water quality standards or in the volume of water needed by a certain number of users. Therefore, the demand for a given RS is equivalent to the amount of water, sediment, or N that society wants regulated to achieve a specific social objective (e.g., a total maximum daily load [TMDL] of a contaminant). RS demand was calculated by subtracting the pre-established water quantity or quality goal (e.g., TMDL) from the inputs, where inputs are measured (or estimated via models, in our case) as the

amount of water, sediment, or N entering the study area. These inputs were derived from (upstream) adjacent lands within the same catchment. The sediment, water, and N exported from DoD lands represent the inputs to downstream communities. RS flow represents the amount of ecological work that actually occurs to produce the service and was calculated by subtracting the quantity or concentration of water, sediment, or N measured in surface waters (at established monitoring stations) from the input estimates derived from our hydrologic models.

Our geospatial analysis was conducted with ArcGIS (Economic and Social Research Institute [ESRI] version 10) but we also included a field validation of the spatial data. All analytical procedures were documented so they can be replicated beyond our demonstration.

## 2.2 METHODOLOGY DEVELOPMENT

Conceptual models reflecting the ecological features and processes that contribute to the capacity of focal ecosystem services were developed prior to this project. Likewise, most of the terminology was developed prior to the demonstration, with the exception of *ecological pressure,* which evolved from concurrent discussions and resulted in a white paper (Villamagna et al. 2013). This paper provides a synthesis of common terminology and explains a rationale and framework for distinguishing among the components of ES delivery. These components include an ecosystem's capacity to produce a service; ecological pressures that interfere with an ecosystem's ability to provide the service; societal demand for the service; and flow of the service to people. The geospatial surface water regulation, vertical N retention, and horizontal sediment retention models were developed prior to this demonstration; however the ArcToolbox interface was developed for this demonstration. The models were developed in ArcGIS 10.0 using on-installation and national-level data sets specific to the project. The data inputs used in this demonstration are provided in Appendix B. We provide illustrations of ArcGIS models that drive the ArcTools and a snapshot of the tool interface for each model in Appendix C.

## 2.3 ADVANTAGES AND LIMITATIONS OF THE METHODOLOGY

Current ES assessment methods range from economic valuation to rather simple (but quick) estimates based on land cover proxies and ambient environmental condition. Many analyses focus on the economic valuation of a few ES over small spatial extents. Although knowledge of ecosystem value (economic and other) can lead to corrected market prices and economic incentives for conservation (Kremen and Ostfeld 2005), the reliability of such value estimates is highly dependent on the accuracy and availability of biophysical data, as well as the valuation method used. To expedite valuation, many economic assessments use land cover types as simplified proxies. However, the ecological processes that deliver ES are inherently complex and depend on other physical factors (e.g., soil, slope, precipitation). Further, the value of a particular ES is socially determined and can vary widely across space and time. By relying on land cover

proxies alone, valuation studies assume that areas with the same land cover always deliver the same ES and the same societal benefits (Troy and Wilson 2006). Economic valuations are also often site-specific making them difficult to transfer across landscapes (Plummer 2009).

In addition, ES studies to date rarely distinguish the potential supply of a particular RS (i.e., capacity) from the flow of that RS (i.e., the actual benefits derived from the service), as is suggested with this proposed methodology. Economic valuations of RS often use avoidance and replacement-cost approaches to estimate the cost of providing a service under current conditions (Farber et al. 2006). However, ambient conditions alone do not accurately reflect RS capacity or flow. For example, a watershed's good water quality does not necessarily reflect its high water purification capacity or its high flow of purification service; ecological stressors (e.g., contaminants) that increase demand on water purification processes also play a role. This distinction requires an understanding of an ecosystem's capacity to provide ES and the factors that drive the demand for such services. Demand on a RS (a precursor to RS flow estimation) reflects the amount of ecosystem "work" required to achieve a predetermined goal, as might be established by the Clean Water Act (CWA) for a TMDL. Thus, demand for purification can be measured as the quantity or concentration of contaminant that needs to be excluded or removed from water to meet a management goal. This can be calculated by subtracting the predetermined goal (TMDL) from total inputs. Environmental degradation occurs when demand on RS (e.g., contaminant loading) exceeds RS capacity, as might occur under certain land use scenarios. Approaches that base RS flow on ambient conditions alone may misrepresent capacity because they fail to account for case-specific differences in demand on RS. Instead, RS flow estimates should reflect the actual work or productivity of the system (Peterson et al. 2010), which can be estimated by subtracting the measured ambient condition from the inputs in terms of stressor (e.g., contaminant concentration).

While the advantages of our proposed methodology are numerous, its application is limited by the accuracy and availability of existing data that are already in spatial format or can be translated into a spatial (i.e., GIS) workspace. The quality and reliability of the data will play a large role in determining the accuracy of the analytical results; therefore, we field-validated as much of the spatial data as possible and used these validation studies to incorporate a measure of uncertainty into our results and enhance the methodology's future use. In addition to the reliability of data, this methodology is limited by the involvement, or lack thereof, by DoD installation stakeholders. A major component of this analytical framework is to engage stakeholders (i.e., environmental division managers, mission operators, and decision-makers) in the process of developing scenarios for ES analysis. To do this, the demonstration team and the analysts must clearly understand the details of the operations and future land use in order to accurately parameterize these components within the analytical framework. The methodology is therefore potentially limited by installation personnel involvement and data accessibility related to confidentiality protocols.

# 3.0 PERFORMANCE OBJECTIVES

In this section we outline (Table 1) the quantitative and qualitative performance objectives (POs), metrics, and data requirements; we also define criteria by which we measure our success. Criteria for each PO were developed via review of the scientific literature and iterative conversations with the ESTCP program manager. We sought criteria that were easily quantified and interpreted, as well as defensible in terms of validating performance. For most POs we found no precedents for success criteria; in these cases we developed criteria (vetted by the ESTCP program manager) that we believed to be reasonable and objective measures of performance.

Below, we describe each PO and its relevance to our demonstrations at Fort Picket and Cherry Point. In addition we describe the performance metrics and data requirements for each objective. Throughout the table and narrative description we refer to the *resolution* of the GIS layers. For raster (gridded) data this refers specifically to the cell size (e.g., National Land Cover Dataset [NLCD] 2006 data are 30-m resolution; Fry et al. 2011). For vector (polygon) data, resolution refers to the size of the smallest feature that can be detected. In both cases, we assume a finer resolution provides greater detail and power to make decisions regarding ES capacity, demand, and ambient condition. Improving the spatial resolution of ES inventories is one challenge. A second challenge is to increase the detail that goes into the production functions (i.e., ES capacity equations) to enhance the ecological detail. We refer to this as *production function detail* throughout the demonstration. Production functions are derived from conceptual models for capacity of focal ES. A list of spatial datasets used in the demonstration is in Appendix B.

Table 1: Performance objectives for demonstrations at Fort Pickett and MCAS Cherry Point. LULC = Land use – land cover; SSURGO = Soil Survey Geographic Database; SWAT = Soil and Water Assessment Tool; SPARROW = Spatially Referenced Regressions On Watershed attributes; RUSLE = Revised Universal Soil Loss Equation; NLCD = National Land Cover Dataset.

| Performance Objectives | Metrics | Data Requirements | Success Criteria | Results |
|---|---|---|---|---|
| **Quantitative** | | | | |
| 1. Improve *production function details* of GIS-based analysis of Surface Water Regulation capacity | Percent of *calculation factors* from conceptual model (Figure 12; green boxes) that are included in spatial analysis of ES capacity | Geospatial data including: land cover, soil, elevation, precipitation (see Appendix B for data sources) | - ≤ 33.3% of calculation factors are absent when there are ≤ three calculation factors noted in the Surface Water Regulation capacity conceptual model.<br>- ≤ 50% of calculation factors are absent when there are > three calculation factors noted in the Surface Water Regulation capacity conceptual model | Surface Water Regulation capacity: 100% (3/3) of factors were available at the regional and national scale for Fort Pickett and 100% of the factors were available at the national and local (on installation) scale for Cherry Point |
| 2. Improve *production function details* of GIS-based analysis of Sediment & Nitrogen Regulation capacity | Percent of *calculation factors* from conceptual model (Figure 11; green boxes) that are included in spatial analysis of ES capacity | Same as PO#1 | - ≤ 33.3% of calculation factors are absent when there are ≤ three calculation factors noted in the Sediment & Nitrogen Regulation capacity conceptual model.<br>- ≤ 50% calculation factors are absent when there are > three calculation factors noted in the Sediment & Nitrogen Regulation capacity conceptual model | Sediment & Nitrogen Regulation capacity: 100% (3/3) of factors were available at the regional and national scale for Fort Pickett and 100% of the factors were available at the national and local (installation) scale for Cherry Point |

| Performance Objectives | Metrics | Data Requirements | Success Criteria | Results |
|---|---|---|---|---|
| **Quantitative** | | | | |
| 3. Improve *spatial resolution* of GIS-based analysis of Surface Water Regulation capacity | Resolution of final GIS layer | Same as PO#1 | Area of the smallest parcel of land representing intersecting capacity factors is smaller than LULC resolution (30 m) | The smallest parcel of land representing intersecting capacity factors was <1 $m^2$ in Fort Pickett and in Cherry Point |
| 4. Improve *spatial resolution* of GIS-based analysis of Sediment & Nitrogen Regulation capacity | Resolution of final GIS layer | Same as PO#1 | Area of the smallest parcel of land representing intersecting capacity factors is smaller than LULC resolution (30 m = 900 $m^2$) | **Vertical Retention-** The smallest parcel of land representing intersecting capacity factors was <900 $m^2$ in Fort Pickett and in Cherry Point (see text for more detail) **Horizontal Retention -** The smallest parcel of land representing intersecting capacity factors was 100 $m^2$ in Fort Pickett and in Cherry Point **Riparian filtration -** The smallest parcel of land representing intersecting capacity factors was <300 $m^2$ in Fort Pickett and in Cherry Point (see text for more detail) |

| Performance Objectives | Metrics | Data Requirements | Success Criteria | Results |
|---|---|---|---|---|
| **Quantitative** | | | | |
| 5. Demonstrate transferability of Surface Water Regulation service-related frameworks for measuring capacity, demand on, demand for, and flow | Availability of data inputs from conceptual model (Figure 12; brown boxes) available at functional resolution for Fort Pickett, Cherry Point, and the eight-digit hydrologic units containing Fort Pickett and Cherry Point | Geospatial data same as PO#1 for<br>a) Fort Pickett,<br>b) eight-digit hydrologic units containing Fort Pickett,<br>c) Cherry Point,<br>d) eight-digit hydrologic units containing Cherry Point | a) No more than one dataset is absent for the within-installation or hydrologic unit analyses<br>b) no more than two datasets are of lower resolution than within-installation data inputs | All datasets for capacity were present at low resolution, and all but one dataset was available at the installation level (precipitation). In some cases, the national dataset was the highest resolution (e.g., SSURGO). The LULC data set was not available at the installation level, but we synthesized multiple datasets to create it. Ambient condition data (for ecological pressure assessment) was not available from the installations and the precipitation data for Fort Pickett came from > 30 miles away |
| 6. Demonstrate transferability of Sediment & Nitrogen Regulation service-related frameworks for measuring capacity, demand on, demand for, and flow | Availability of data inputs from conceptual model (Figure 11; brown boxes) available at functional resolution for areas within the same 8-digit hydrologic units and available for both demonstration installations | Same as PO#5 | a) No more than one dataset is absent for within-installation or hydrologic unit analyses<br>b) no more than two datasets are of lower resolution than within-installation data inputs | All datasets for capacity were present at low resolution, and all but one dataset was available at the installation level (precipitation). In some cases, the national dataset was the highest resolution (e.g., SSURGO). The LULC data set was not available at the installation level, but we synthesized multiple datasets to create it. Ambient condition data was not available from Cherry Point and the precipitation data for Fort Pickett came from > 30 miles away |

| Performance Objectives | Metrics | Data Requirements | Success Criteria | Results |
|---|---|---|---|---|
| **Quantitative** | | | | |
| 7. Demonstrate framework to rank ecological pressure on RS | Percent congruency between ecological pressure estimates using our approach and those based on full-scale hydrologic modeling | Data inputs required for SWAT or SPARROW model, RUSLE | Estimated ecological demand is within 10% of modeled ecological pressure (i.e., 90% or more of classifications measured by area are shared between approaches | We produced maps illustrating the overlap (% congruency) among ecological pressure indicators based on three levels of data processing and time investment for Sediment & Nitrogen Regulation and Surface Water Regulation. N monitoring data were not available |
| 8. Demonstrate how to measure flow of RS to beneficiaries | Spatially-explicit statistical similarity (tested with chi-square) between expected and observed values of RS capacity, demand on RS, ambient condition, and measured flow | geospatial layers for: a) two focal services capacity, b) ecological pressure on RS, c) ambient condition, and d) estimates of RS flow | *Modified*^: ≥ one map/installation illustrates the flow of services and pressures from on-installation training areas and table that prioritizes compatible buffer land parcels impacted by on-installation land use and RS | Two maps were produced for each installation showing the flow of ecological pressures (erosion/sediment loading, surface water runoff) and buffer lands were ranked based on their contribution to installation ES and their ability to mitigate ecological pressures |
| 9. Demonstrate minimal propagation errors in geospatial data | Estimates of post-field-validated capacity based on reclassified land cover and capacity range estimates based on producer/user accuracy estimates for land cover data | NLCD 2006 data, installation land cover data | Capacity estimates based on post-field-validation and reclassified data fall within confidence intervals produced from data-source accuracy assessments | Land cover data were largely out of date on both installations. We noted trends of inaccuracy that reflected primary succession (barren to forest) and construction (forest to grassland)<br>(See text for more detail) |
| 10. Enhance ES-based decision support systems | Number of ArcTools and/or scripts created to facilitate ES inventory process | ArcGIS model builder and geospatial data listed in Appendix B | At least one tool/script for each ES analyzed | 4 ArcTools were developed for Sediment & Nitrogen Regulation and two ArcTools were developed for Surface Water Regulation |

| Performance Objectives | Metrics | Data Requirements | Success Criteria | Results |
|---|---|---|---|---|
| **Qualitative** | | | | |
| 11. Demonstrate utility of a framework for integrating RS into natural resource and mission planning decisions | a) Survey response by GIS Analysts and Natural Resource Managers to evaluate ease of use | a) Feedback from GIS Analysts and Natural Resources Managers at Fort Pickett and Cherry Point | a) Mean survey response from analysts and natural resource managers >1.5 using scorecard approach, indicating that the framework and GIS tools provided are helpful and user-friendly | Mean survey response was 3.0 for Cherry Point and 2.5 for Fort Pickett. Results indicate that framework and tools are easy to use |
| | b) Survey response by decision-makers and planners to evaluate the utility of products from the framework demonstrated | b) Feedback from decision-makers and planners at Fort Pickett and Cherry Point | b) Mean survey response from decision-makers and planners >1.5 using scorecard approach, indicating that the analytical framework demonstrated can help with environmental compliance and land-use planning | Mean survey response was 3.0 for Cherry Point and 2.6 for Fort Pickett. Results indicate that framework and tools are useful in the context of installation compliance and planning |
| 12. Improve projections of RS | Survey response from scenario-workshop participants | Feedback from workshop participants at Fort Pickett and Cherry Point | Mean survey response from workshop participants >1.5 using scorecard approach, indicating that the scenario-generating process and the analyses produced from the workshop-developed scenarios are useful to decision-making | Mean survey response was 3.0 for Cherry Point and 2.3 for Fort Pickett. Results indicate that scenarios and resulting analyses are useful in the context of installation compliance and planning |

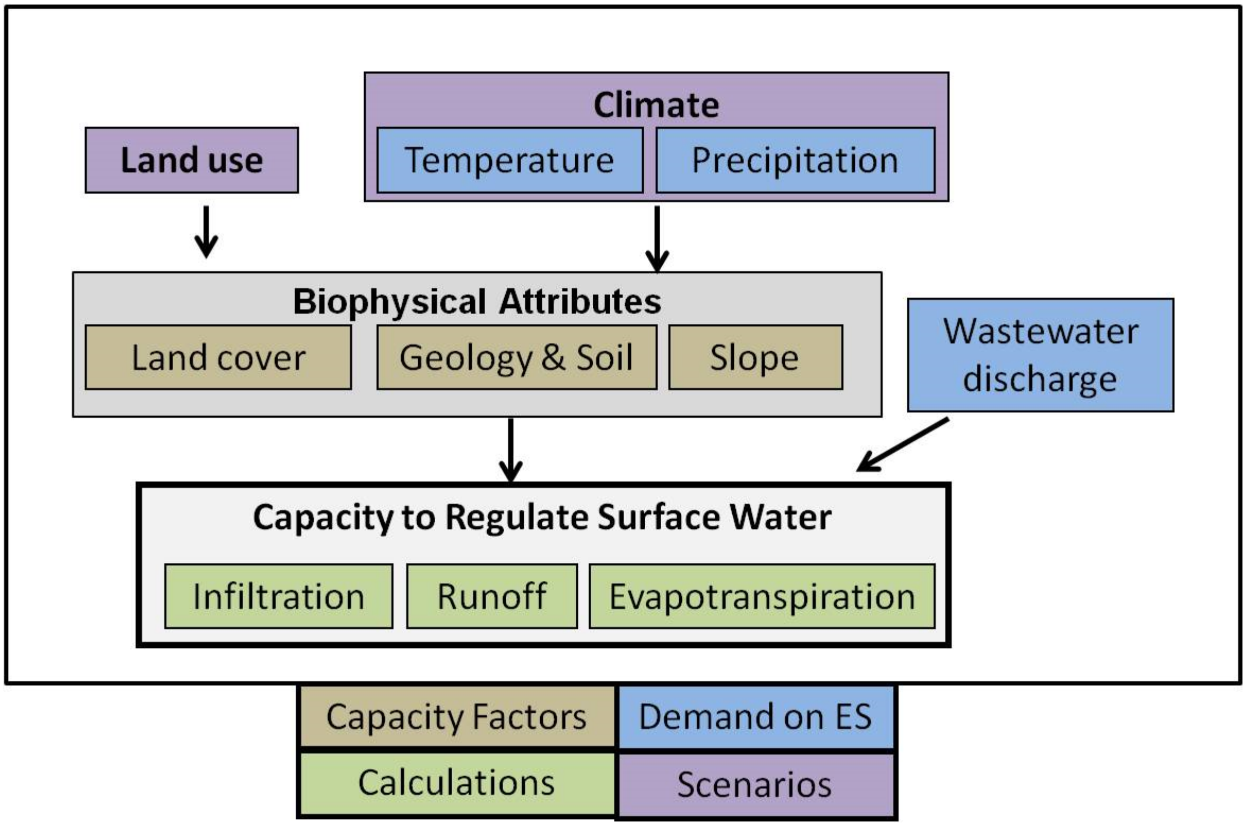
^ Modified due to the lack of installation-level ambient condition data and installation interest in identifying where impacts from installation are experienced.

## 3.1 PERFORMANCE OBJECTIVE # 1: IMPROVE PRODUCTION FUNCTION DETAILS OF GIS-BASED ANALYSIS OF SURFACE WATER REGULATION CAPACITY

Create mappable production functions of Surface Water Regulation capacity. This objective is based on the assumption that land cover alone is not a reliable predictor of spatial variation in ES at the installation scale. Production functions for RS should include multiple layers of relevant data in addition to land cover data, commonly used as a surrogate for ecological processes. Improvements in production function detail will be measured by the percent of calculation factors from the capacity conceptual model (Figure 2; green boxes) included in the spatial analysis. No more than 33% of the described calculation factors should be absent from the capacity analysis when three or fewer calculations are defined. When there are more than three calculation factors described in the conceptual model, more than 50% of the calculation factors should be present and accounted for in the capacity analysis. There are currently three calculation factors defined for Surface Water Regulation capacity, therefore we should include at least two calculations in the capacity analysis. This will offer an improvement in production function detail because each calculation involves more than one data input (e.g., land cover).

We were successful in that all three factors in the Surface Water Regulation capacity model were available at the national and regional scales for both installations.

**Figure 2: Conceptual model illustrating factors that influence Surface Water Regulation (SWR) capacity. Brown-box factors identify data inputs, green-box factors include potential calculations within the production function, blue-box factors represent potential sources of demand on SWR, and purple-box factors represent anthropogenic points of influence that can be modeled through scenario analysis.**

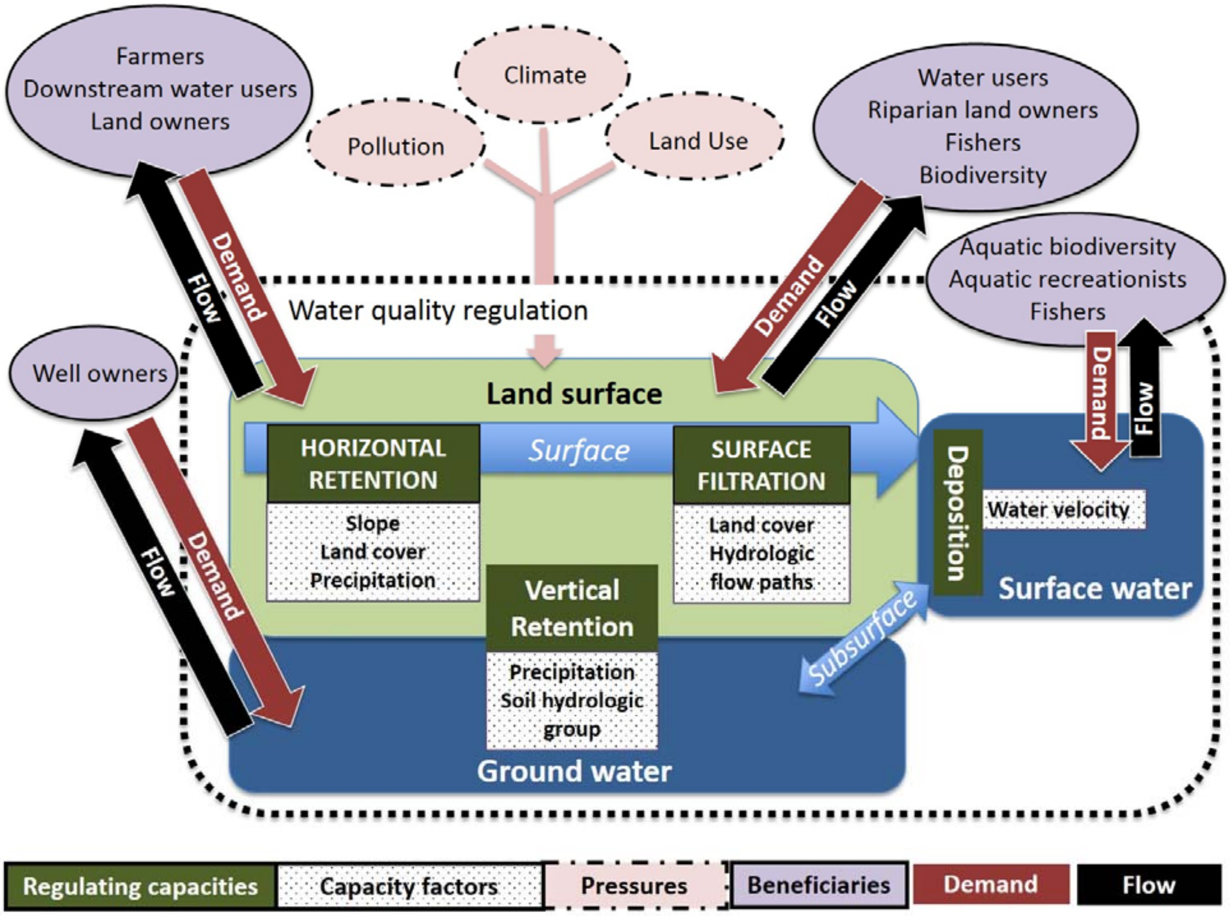



## 3.2 PERFORMANCE OBJECTIVE # 2: IMPROVE PRODUCTION FUNCTION DETAILS OF GIS-BASED ANALYSIS OF SEDIMENT & NITROGEN REGULATION CAPACITY

Create mappable production functions of Sediment & Nitrogen Regulation capacity. This objective is analogous to PO #1. There are currently four calculation factors described in the Sediment & Nitrogen Regulation capacity model (Figure 3; green boxes), therefore we should include at least two of the calculation factors. This will offer an improvement in production function detail because each calculation involves more than one data input.

We were successful in that all three factors in the Sediment & Nitrogen Regulation Capacity model were available at the national and regional scales for both installations.

**Figure 3: Conceptual model illustrating factors that influence Sediment & Nitrogen Regulation (SNR) capacity. Brown-box factors identify data inputs, blue-box factors represent potential sources of demand on SNR, and green-box factors include potential calculations within the production function.**




## 3.3 PERFORMANCE OBJECTIVE # 3: IMPROVE SPATIAL RESOLUTION OF GIS-BASED ANALYSIS OF SURFACE WATER REGULATION CAPACITY

Create geospatial Surface Water Regulation capacity data layers that provide greater detail than land cover data layers. Spatial resolution is measured by cell size in raster data and by the size of the smallest detectable feature in vector data. The resolution of the final capacity layer representing the production function is important and should provide the greatest resolution to GIS analysts, natural resource managers, and DoD decision-makers as possible. The objective is to increase the resolution of ES capacity layers so that they can be used at the installation scale (30-70 $mi^2$). Many assessments of ES provision to date have relied solely on nationally-available land cover data ($\geq$ 30-m resolution). This demonstration will be considered successful if it produces final capacity data layers in which the area of the smallest parcel of land representing intersecting capacity factors is < 900$m^2$, the standard land cover resolution. The resolution of the

resulting capacity layers may be increased further if higher-resolution data become available. It is not clear yet if this is the case for Cherry Point.

By including multiple data inputs to estimate ES capacity, we were successful in accounting for greater landscape heterogeneity than land cover alone. This was evident when the resulting ES capacity layers were analyzed and the smallest feature was < 1 $m^2$, which reflects differences in input values between it and neighboring areas and supports the need for the integrative approach demonstrated in this project.

## 3.4 PERFORMANCE OBJECTIVE # 4: IMPROVE SPATIAL RESOLUTION OF GIS-BASED ANALYSIS OF SEDIMENT & NITROGEN REGULATION CAPACITY

Create geospatial Sediment & Nitrogen Regulation capacity data layers that provide greater detail than land cover data layers. The narrative for this PO is shared with PO # 3 above. This PO refers to output from three related ES capacity models: vertical N retention – measure of groundwater protection; soil retention – relative measure of erosion control; and riparian filtration – measure of expected N and sediment filtration. We were successful in increasing the spatial resolution of ES capacity data for two of the three focal ES (soil retention and riparian filtration). While the spatial resolution of the third ES was equal to our objective (900 $m^2$), we consider the informational resolution to be enhanced since we used a soil-based algorithm for mapping leaching probability that was adapted for the various soil hydrological groups present on our focal installations.

## 3.5 PERFORMANCE OBJECTIVE # 5: DEMONSTRATE TRANSFERABILITY OF SURFACE WATER REGULATION SERVICE-RELATED FRAMEWORKS FOR MEASURING CAPACITY, ECOLOGICAL PRESSURE, DEMAND FOR, AND FLOW

Develop mappable RS production functions based on widely available data that are easily mapped. The goal of this framework is to provide an approach to assessing ES systematically across a wide range of landscapes (i.e., spatial extent) and spatial scales (i.e., resolution). For these approaches to be transferable to other DoD installations and surrounding areas, we aim to produce mappable production functions that are based on data widely available at the national or regional scale, but that also can incorporate finer-resolution local data (see POs #3 & 4). We will demonstrate the transferability of this approach by applying the Surface Water Regulation capacity production function to the entire 8-digit hydrologic unit containing Fort Pickett and Cherry Point. Our framework will be considered successful if no more than one outside dataset is absent for the within-installation or hydrologic unit analyses, and no more than two data inputs are of lower resolution than within-installation data inputs. If all data are not available, we will demonstrate how alternatives can be used to fill the gaps until the data can be collected.

We were able to gather data for all Surface Water Regulation analyses, both inside the installation boundaries and in neighboring areas. The data included a combination of public data available across the US as well as installation-specific data. An installation-specific LULC GIS dataset was not available, so we synthesized multiple installation-specific datasets to create it (using the Create Land Use Land Cover tool). Precipitation data were available from public sources (PRISM [Parameter-elevation Regressions on Independent Slopes Model] Climate Group) and we were able to apply local rain gage data from Cherry Point to demonstrate transferability of capacity, ecological pressure, demand, and flow models. Thus, we conclude that the Surface Water Regulation model was transferrable across installation boundaries.

## 3.6 PERFORMANCE OBJECTIVE # 6: DEMONSTRATE TRANSFERABILITY OF SEDIMENT & NITROGEN REGULATION SERVICE-RELATED FRAMEWORKS FOR MEASURING CAPACITY, ECOLOGICAL PRESSURE, DEMAND FOR, AND FLOW

<u>Develop mappable RS production functions based on widely available data that are easily mapped.</u> The narrative for this PO is shared with PO #5, but applies to the Sediment & Nitrogen Regulation capacity functions within-installations and the 8-digit hydrologic unit containing the installations. We were able to gather data for all Sediment and Nitrogen Regulation analyses, both inside the installation boundaries and in neighboring areas. The data included a combination of public data available across the US as well as installation-specific data. An installation-specific LULC GIS dataset was not available, so we synthesized multiple installation-specific datasets to create it (using the Create Land Use Land Cover tool). On-installation LULC data were seamlessly integrated into a LULC dataset for the 8-digit hydrologic unit, further demonstrating the flexibility and transferability of our models. Precipitation data needed for the Vertical N Retention and Riparian Filtration models were available from public sources (PRISM Climate Group) and we were able to apply local rain gage data from Cherry Point to demonstrate transferability of capacity, ecological pressure, demand, and flow models. Thus, we conclude that the Sediment & Nitrogen Regulation capacity function was transferrable across installation boundaries.

## 3.7 PERFORMANCE OBJECTIVE #7: DEMONSTRATE AN ACCURATE FRAMEWORK FOR MEASURING RELATIVE ECOLOGICAL PRESSURE ON RS THAT IS LESS FIELD DATA- AND TIME-INTENSIVE THAN FULL-SCALE HYDROLOGICAL MODELING APPROACHES

<u>Measure the relative difference between estimates from our approach and results from full-scale hydrologic modeling approaches.</u> A goal of this framework is to provide an assessment approach that produces an inventory of ES based on relative values within a small geographic scope (e.g.,

within an individual installation). While ecological demand (i.e., nutrient, sediment, contaminant loading) can be measured in the field or using full-scale hydrologic models like SPARROW or SWAT, we aim to demonstrate a much less data- and time-intensive approach that produces relative values of ecological demand that are instructive in making planning decisions. Our approach will be considered successful if it estimates ecological demand within 10% of modeled demand. In other words, 90% or more of classifications (measured by area) are shared between approaches.

We produced maps illustrating the overlap (% congruency) among ecological pressure indicators based on three levels of data processing and time investment for Sediment regulation and Surface flooding. Nitrogen monitoring data were not available at either installation. The results based on a comparison of LULC and model-based predictions to Cherry Point surface water flooding and Fort Picket erosion observation (2008 survey) suggested that our predictive approaches were partially successful. There was less than 90% overlap between predicted and observed erosion (68% and 82% for model and LULC predictions, respectively) but 100% overlaps between LULC and surface water yield (SWY) models and observed surface flooding at Cherry Point. This suggests that LULC may be an adequate proxy for quickly assessing areas of low surface water regulation (i.e., high surface water yield). If we accept the erosion points observed in 2008 as representative, our results suggest that LULC is a more accurate proxy for predicting erosion.

### 3.8 PERFORMANCE OBJECTIVE #8: DEMONSTRATE FRAMEWORK FOR MEASURING CURRENT FLOW OF RS IN TERMS OF ECOLOGICAL WORK

Create a mappable function that defines RS flow as ecological work. While flow for provisioning services is commonly measured by the number of people affected or total human consumption, the relationships between RS and humans are less direct, and hence more difficult to measure with consumption statistics. In the past, land cover or ambient condition have been used as surrogates to represent RS flows, but neither measured alone is an accurate reflection of the regulation occurring since ambient condition depends on the capacity of the system (in part related to land cover) and the ecological demand on the system (Figure 4 and Table 2). We proposed to test our method for measuring RS flow in terms of ecological work by comparing the observed relationships among RS capacity, ecological demand, ambient condition, and measured flow to the expected relationships.

**Figure 4: Relations among ecosystem stress, ambient condition, and regulating service (RS) capacity. In a system with no RS capacity (a), condition degrades quickly with increasing stress and may be acceptable under only low stress. In a system with low RS capacity (b), the ecosystem can do some "work" to maintain condition despite increasing stress but is overwhelmed if stress reaches moderate levels. In a system with high RS capacity (c), conditions become unacceptable only at very high levels of stress. Ecosystem work represents RS flow. As shown here, ambient condition is a function of RS capacity and the stress (or demand) on the regulating processes.**

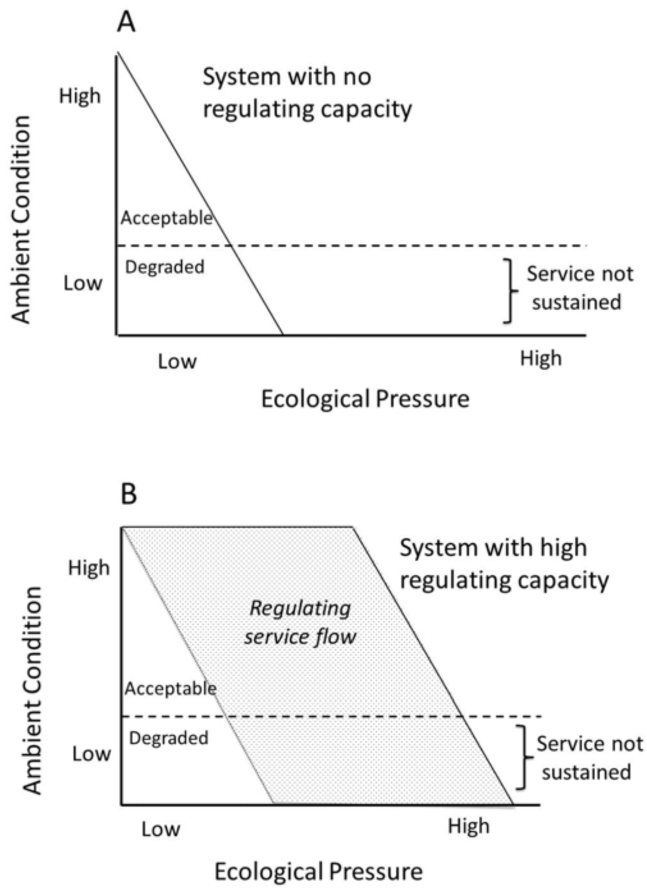


**Table 2: Expected relationships among RS capacity, ecological pressure, ambient condition, and flow of RS measured in terms of ecological work (also see Figure 4).**

| RS Capacity | Ecological Pressure | Ambient Condition | RS Flow |
|---|---|---|---|
| High | High | Moderate | High |
| | Low | High | Low-Moderate |
| Low | High | Low | Moderate |
| | Low | Moderate - High | Low |

We were unable to fully demonstrate the method for measuring RS flow based on the ecological work done by ecosystems that takes into account capacity and ecological demand (i.e., stress) largely because the installations did not have a reliable source of ambient condition data for N or stream discharge. Therefore, we adapted our approach to focus on the flow of riparian filtration services by comparing upland estimates of soil loss to instream measures of turbidity and total suspended solids, two commonly used metrics of sediment loads. This demonstration was conducted at Fort Pickett. Despite the adaptation, we feel we were unsuccessful in demonstrating the full potential of this approach because available field data were *i)* sparse, and *ii)* collected using inconsistent methods. A more in-depth discussion of our demonstration is provided in section 6.8.

### 3.9 PERFORMANCE OBJECTIVE # 9: DEMONSTRATE MINIMAL PROPAGATION ERRORS IN GEOSPATIAL DATA

Incorporate geospatial data-producer accuracy assessments into capacity estimates to decrease data propagation error. Much of the proposed spatial analyses depend on remotely sensed land-cover data and subsampling protocols. To reduce the propagation of errors associated with geospatial inputs, we account for potential inaccuracy by incorporating measures of producer accuracy into our calculations to produce an estimated range of capacity. To demonstrate how this method will account for spatial uncertainty, we will conduct field validation for spatial data and, where necessary, reclassify land cover to match field assessment. Once land cover is updated, we will recalculate capacity to produce a single value rather than a range. If our reclassified estimates fall within the confidence intervals of our initial estimates, we will consider our approach successful in saving time and money.

This objective was partially met. We conducted a field validation of land cover, summarized the results, and examined how the land classification errors would impact current and future estimates of RS capacity.

## 3.10 PERFORMANCE OBJECTIVE #10: ENHANCE ES-BASED DECISION SUPPORT SYSTEMS

Produce and demonstrate ArcGIS-based tools to facilitate the assessment and mapping of RS. Decision-support tools that focus on ES are currently limited (e.g., InVest) and their use by in-house analysts is often restricted by institutional security. We measured success in this PO by counting the number of tools produced; success means producing at least one tool or ArcScript that facilitates the calculation of RS.

We were highly successful in meeting this objective; we developed one to three ArcGIS tools for each of the focal RS, as well as tools to help synthesize land cover data into a single dataset and create land use change scenarios.

## 3.11 PERFORMANCE OBJECTIVE #11: DEMONSTRATE UTILITY OF A FRAMEWORK FOR INTEGRATING RS INTO NATURAL RESOURCE AND MISSION PLANNING DECISIONS

a) Assess ease-of-use by GIS Analysts and/or Natural Resource Managers. In addition to producing the ArcGIS-based tools, we assessed ease-of-use to ensure that our end-products will be of use to DoD personnel in the future. Ease-of-use was evaluated via a scorecard approach based on a survey in which analysts and managers answered questions regarding the usefulness and user-friendliness of the framework and GIS tools. Responses were scaled from 1 to 3 as follows: 3) the demonstrated framework and GIS tools are adequate, helpful, and user-friendly, 2) the demonstrated framework and GIS tools are generally helpful, but the GIS interface could be more user-friendly, and 1) the demonstrated framework and GIS tools are inadequate and difficult to use. We consider this objective to be met if the mean score of the surveyed analysts and managers is >1.5, indicating that the demonstrated framework and GIS tools provided are helpful and user-friendly, given supportive training materials (i.e., end-user workshop and materials).

a) Assess utility of framework for integrating RS into natural resource and mission planning. We measured the utility of our RS framework and end-user tools via a scorecard approach based on a survey in which installation staff involved in planning and decision-making answered questions regarding the utility the framework. Responses were scaled from 1 to 3 as follows: 3) the demonstrated framework exceeds expectations, and will definitely help environmental compliance and ecosystem-level planning, 2) the demonstrated framework is adequate and may be helpful towards achieving environmental compliance and ecosystem-level planning, and 1) the demonstrated framework is inadequate and not worth implementing. We consider this objective to be met if the mean score of the surveyed analysts and managers is >1.5, indicating

that surveyed planners and decision-makers agree that our analytical framework can help with environmental compliance and ecosystem-level planning.

We revised our proposed end-of-project survey design to reflect our engagement with installation staff and their time constraints relative to our project. Given the involvement of only a few installation personnel throughout the project, we combined analysts, managers, planners, and decision-makers into the same survey and gave all of them the same questions. Because most respondents chose to remain anonymous, we could not distinguish responses among analysts, managers, planners, and decision-makers. Further, we shortened the response scale from 1-4 to 1-3 to reduce the time needed to complete the survey. We designed the survey to evaluate five important components of the demonstration, including performance aspects related to: 1) ease of using demonstrated framework and tools, 2) utility of ES concepts and framework, 3) advances in ES knowledge via the demonstration, 4) utility of scenario analysis (toward PO #12), and 5) engagement of the demonstration team with installation staff. We met this PO successfully with mean scores > 2.2 for all five aspects.

### 3.12 PERFORMANCE OBJECTIVE #12: IMPROVE FORECASTING OF RS

<u>Develop projections of RS capacity based on future scenario workshops.</u> Future scenarios with respect to ES are largely driven by management-induced land use changes, as well as widespread climate changes. By including the decision-makers in the development of these scenarios, we believe projections will be improved. The future scenario workshops were evaluated via a scorecard approach based on survey questions in which workshop participants answered a set of questions regarding the usefulness of the scenario workshop and the products produced. Reponses were scaled from 1 to 3 as follows: 3) scenario-analysis workshop and analytical products (e.g., scenario maps) exceed expectations, and will definitely help the installation achieve and maintain environmental compliance and ecosystem-level planning, 2) scenario-analysis workshop and analytical products are adequate and may be helpful towards achieving environmental compliance and ecosystem-level planning, and 1) scenario-analysis workshop and analytical products are inadequate and not worth the investment. We consider this objective to be met if the mean score of the workshop participants is >1.5, indicating that participants agree that the scenario-generating process and analyses produced from the workshop-developed scenarios are useful in planning and decision-making.

As described above, we revised our proposed end-of-project survey design to reflect our engagement with installation staff and their time constraints relative to our project. Given the involvement of only a few installation personnel throughout the project, we combined analysts, managers, and planners into the same survey and gave all of them the same questions. We initially expected off-installation stakeholders (e.g., from regulatory agencies and/or neighboring communities) to participate in scenario workshops but installation staff decided against this

participation. Thus, workshops included only a few on-installation participants. Because most respondents chose to remain anonymous, we could not distinguish responses among analysts, managers, and planners. Further, we shortened the response scale from 1-4 to 1-3 to reduce the time needed to complete the survey. We included questions on the aforementioned survey to explicitly evaluate performance aspects related to the utility of scenario analysis. We met this PO successfully with a mean score of 2.3 and 3.0 at Fort Pickett and Cherry Point, respectively.

# 4.0 SITE DESCRIPTION

In the sections to follow we describe salient features of ANG-MTC Fort Pickett and MCAS Cherry Point, the two installations selected for this demonstration.

## 4.1 SITE LOCATION AND HISTORY

ANG-MTC Fort Pickett is located in southeastern Virginia, approximately 62 miles southwest of Richmond and 3 miles east of the town of Blackstone. The installation is within the Piedmont physiographic province and intercepts the counties of Nottoway (21,360 ac), Brunswick (6,533 ac) and Dinwiddie (13,091 ac). Fort Pickett has a diverse history of closings and status changes, the most recent in 1997 as a result of Base Realignment and Closure. During this time, the operation of Fort Pickett was given to the Virginia National Guard and the installation was renamed the Army National Guard Maneuver Training Center-Fort Pickett, which now provides an assortment of training facilities as well as interspersed buffer zones for various live-fire exercises.

MCAS Cherry Point, comprising approximately 19,200 acres, is located on the coast of North Carolina and was created by an act of Congress in 1941. MCAS Cherry Point is an installation complex that contains properties in three eastern counties: Carteret, Jones, and Pamlico. MCAS Cherry Point is the primary airfield for Marine Corps aviation on the east coast of the US. It maintains, operates, and provides support for the operations of the 2$^{nd}$ Marine Aircraft Wing.

ANG-MTC Fort Pickett and MCAS Cherry Point were selected as demonstration sites for this ES assessment methodology because they 1) are large DoD properties within the geographic focus of concurrent ES research (i.e., the Albemarle-Pamlico basin), 2) face significant land-use and climate changes over the next few decades, 3) rely on sediment and nitrogen regulation and surface water regulation services to pursue their missions, 4) support several imperiled aquatic species that will likely be affected by changes in RS capacity, 5) interact with stakeholders (e.g., state agencies and neighboring communities) to manage surface water quality and quantity and 6) have existing spatial data to be used in the proposed demonstration. These sites were chosen because they offer the opportunity to apply the methodology at a finer resolution and to help guide decisions concerning land use and military operations and stewardship. Both installations face encroaching human population growth in adjacent areas that threaten the full range of military operations supported by each. In addition, ANG-MTC Fort Pickett faces water quality and endangered species-related issues that make it an appropriate demonstration site for our focal RS.

## 4.2 SITE CHARACTERISTICS

Topography within ANG-MTC Fort Pickett is typical of the Piedmont, with gently rolling terrain dissected by stream drainages. Within the installation, elevation ranges between 61 m above sea level along the Nottoway River and around 137 m just north of the Blackstone Army Airfield.

Most of ANG-MTC Fort Pickett is within the Nottoway River basin which initially flows east then joins the Blackwater River near the VA-NC border to create the Chowan River, which drains into the Albemarle Sound. The Nottaway River is non-tidal, within Coastal Plain and Piedmont physiographic provinces, and mostly meets water quality standards of the US Clean Water Act. However the segment of the river and its tributaries that cross ANG-MTC Fort Pickett (VAC-K16R_ZZZ01A00) are listed as Category 3 by Virginia Department of Environmental Quality (VADEQ) because there are not enough publicly available data to determine if designated uses are supported. Several stream segments that originate on or cross the installation are designated as Category 5 by the Unites States Environmental Protection Agency (USEPA) and therefore require the development of a TMDL plan (Fort Pickett Integrated Natural Resources Management Plan [INRMP]).

Soils at Fort Pickett generally consist of a quartz sandy loam surface layer 15-46 cm deep over a micaceous clay loam, with a frost depth of 61 cm (Fort Pickett INRMP). The majority of upland soils has a slow to moderate infiltration rate and is non-hydric. Loams and sandy loams are the most common soil types on ANG-MTC Fort Pickett. In addition, there are four wetland soils found on ANG-MTC Fort Pickett: Chewacla, Wehadkee, Worsham and Chastain (Gravatt et al. 1999, cited in Fort Pickett INRMP). These wetland soils are generally found on low slopes (0-2%) and have slow infiltration rates (Fort Pickett INRMP).

At MCAS-Cherry Point, elevation ranges from near sea level along Neuse River, Slocum Creek, and Hancock Creek to 25-33 feet on the terraces between stream systems. MCAS Cherry Point is located entirely within the Neuse River basin and contains approximately 1600 acres of wetlands. There are 21 soil types represented, 17 of which cover most of the installation, mostly loamy sand. Loamy soils cause much of MCAS Cherry Point to experience poor drainage. Many small tributary streams on-site are ground-water fed and flow intermittently throughout the year. Neuse River, Slocum Creek, Hancock Creek are subject to tidal fluctuations, largely wind driven. Land cover within MCAS Cherry Point varies among pine forests, lower-slope mixed hardwoods, inland floodplain swamp forests, freshwater marshes, and coastal fringe forests. Loblolly Pine stands dominate the forested areas and these stands are burned via prescribed fires every 3-5 years. Longleaf Pine, the historically dominant tree species, is less common but is

being reestablished throughout the site through restoration efforts (MCAS-Cherry Point INRMP).

# 5.0 TEST DESIGN

Two sites have been selected for this demonstration. We present the test designs for MCAS Cherry Point and ANG-MTC Fort Pickett together in the sections below. Timelines for major demonstration tasks are shown in Table 3.

**Table 3: Timelines for major demonstration tasks**

| Tasks | Began | Ended |
|---|---|---|
| Develop decision making framework | March 2013 | August 2014 |
| Introduction to ecosystem service assessment on-site | March 2012 | March 2012 |
| Conduct baseline assessments (capacity, ecological pressure, and flow) | March 2012 | June 2014 |
| Develop ArcTools for baseline analysis | May 2012 | August 2014 |
| Field data collection | March 2013 | September 2014 |
| LULC accuracy assessment | March 2013 | September 2014 |
| Present baseline results | March 2013 | |
| Conduct hydrologic modeling (NRCS Curve Number method and GIS-adapted RUSLE) | May 2012 | July 2014 |
| Compare methods for ecological pressure mapping | April 2014 | August 2014 |
| Scenario development workshop (Fort Pickett) | March 2013 | March 2013 |
| Scenario development workshop (Cherry Point) | August 2013 | August 2013 |
| Parameterize, model, and interpret scenarios | March 2013 | June 2014 |
| Present scenario analysis, land use accuracy, and ArcTools | July 2014 | October 2014 |
| Evaluate decision-maker and GIS analyst utility and tool ease of use | July 2014 | October 2014 |

## 5.1 CONCEPTUAL TEST DESIGN

The conceptual framework and approach will be demonstrated at Fort Pickett and Cherry Point. While this approach has been initiated at a larger scale for the entire Albemarle-Pamlico basin, this demonstration will include higher-resolution spatial data that will enable the scenarios to reflect a more detailed view of landscape dynamics. The higher-resolution questions and data enabled us to create spatial tools that will provide decision makers with more accurate answers concerning the potential effects of land management on RS, ecological resilience, and installation objectives (e.g., compliance with Endangered Species Act [ESA] and CWA).

## 5.2 BASELINE CHARACTERIZATION AND PREPARATION

Baseline maps of ES capacity were created during the first year of the demonstration. Ecological pressures were mapped first using LULC data, then by identifying important thresholds within models (e.g., > 5 tons per acre of soil loss). These maps were produced using LULC data compiled by the Natural Capital Project team (collaborator on the demonstration at Fort Pickett), NLCD land cover, SSURGO soil, PRISM precipitation, and USGS precipitation data, and served as a baseline for the scenario analyses to help a) prioritize lands in the Army Compatible Use Buffer (ACUB) and Environmental Partnerships (EP) programs based on RS capacities and b) manage riparian zones at Fort Pickett based on ecological pressure-flow dynamics).

## 5.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHODOLOGY COMPONENTS

The analytical framework for assessing RS was demonstrated at both sites concurrently; however, the timing for various POs was not synchronized. This was both planned and an unplanned result of communication lags with both installations. We presented our methodology and results to installation personnel, including those within the environmental divisions and those responsible for military operation decisions, at both installations three times during the demonstration.

During out first site visit we provided an overview of RS models, their functionality, data needs, and practical application of results. On-site personnel provided us with (*i*) points of contacts for various data needs, (*ii*) the existing GIS database, (*iii*) and information regarding the chain of command and flow of information between the environmental divisions and mission operations. We conducted the bulk of our baseline analysis of capacity and ecological pressure prior to our second meeting. During the second meeting we presented preliminary results from our RS capacity and ecological pressure models and conducted group and individual discussions regarding potential scenarios that demonstrate the utility of our RS tools. During this time we became aware that it was valuable to demonstrate how RS models could be incorporated into current land management and encroachment mitigation strategies. Rather than simply demonstrate changes in RS capacity and ecological pressure under various land use and climate

conditions, we developed prioritization frameworks for encroachment buffers (i.e., potential land acquisition and easement sites) based on RS capacity and flow of specific parcels bordering both installations.

## 5.4 FIELD TESTING

The field testing of this methodology occurred via the on-installation presentations described in the preceding section.

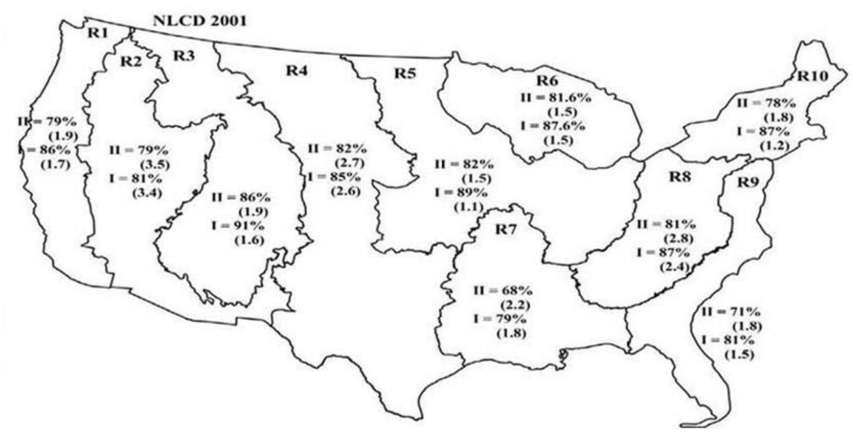
## 5.5 SAMPLING PROTOCOL

Remotely sensed data may come with errors generated during their production. The accuracy associated with geospatial data is an important consideration for all planning decisions, and should be incorporated into estimates of ES capacity. A full list of producer and user accuracy estimates for the NLCD 2001 land cover classes and a map of the US that illustrates accuracy across regions is provide in Figure 5. We conducted field validation of land cover data to estimate user accuracy (i.e., probability that land cover labels in data layer match field data) and producer accuracy (i.e., probability that land cover of an area is correctly classified from satellite imagery). We randomly selected points within the study sites (i.e., Fort Pickett and Cherry Point) to collect field data (e.g., land cover) to compare to corresponding spatial data sets. Selection of field observation points was stratified by land cover class and the area sampled in the field. For all datasets, at least five observations per major land-cover type were sampled. We developed a confusion matrix for both installations to quantify the uncertainty associated with the installation-specific data and compared this to the producer and user accuracy of the NLCD dataset (Figure 5). We also characterized the results from field validation to determine whether baseline RS assessments under- or overestimated capacity.

Since this portion of the demonstration was completed, the accuracy assessment of the 2006 NLCD became available (Wickham et al. 2013). According to Wickham et al. (2013), overall accuracy was 79% ± 0.8% for the entire US and 96% ± 1% for region 9. Wetlands, both emergent and woody, had relatively low producer accuracy (69% ± 6% and 53% ± 11% respectively) and low user accuracy (29% ± 2% and 39% ± 2%). This suggests that we can expect only 29-39% of pixels classified as wetlands in the NLCD to actually be wetlands on the ground and that 53-69% of all wetlands were classified as wetlands by the producers of NLCD. Given this high level of uncertainty, we recommend incorporating local LULC data, especially for wetlands, in composite LULC data as we have done in Fort Pickett and Cherry Point. This data set should be validated and updated annually to ensure accuracy and minimize model propagation error. Results from this are reported in Section 6.9.

**Figure 5: Regional user's accuracy for NLCD 2001 adapted from Wickham et al. (2010). MCAS Cherry Point and ANG-NTC Fort Pickett are located in Region 9. The table provides estimates of producer and user accuracy based on level II land cover classifications. Producer accuracy measures omission errors which can be calculated as the number of parcels correctly identified in reference sites divided by number of parcels in the reference class. User accuracy measures inclusion errors and is represented as the number of correctly classified land cover parcels divided by number of parcels mapped as the given land cover class. "Center" is the land-cover label of pixels selected in samples.**

| Level II | | Producer's Accuracy | User's Accuracy |
|---|---|---|---|
| **Grid code** | **Land Cover Class (NLCD 2001)** | **Center** | **Center** |
| 11 | open water | 70.6 | 94.2 |
| 21 | open space | 45.2 | 76 |
| 22 | low development | 69.5 | 67 |
| 23 | medium development | 73.7 | 95 |
| 24 | high development | 50 | 16 |
| 31 | barren | 23.8 | 67 |
| 42 | deciduous forest | 75.2 | 84 |
| 43 | mixed forest | 82.4 | 80 |
| 52 | shrublands | 37.3 | 58 |
| 71 | grassland/herbaceous | 26.5 | 25 |
| 81 | pasture/hay | 53.9 | 61 |
| 82 | row crops | 82.1 | 80 |
| 90 | herbaceous wetlands | 86.4 | 57 |
| 95 | forested wetlands | 92.5 | 42 |
| | *OVERALL* | 74.2 | 69.7 |



## 5.6 SAMPLING RESULTS

Field sampling was a component of our Performance Objective #9. We discuss results of the sampling protocol described above in section 6.9.

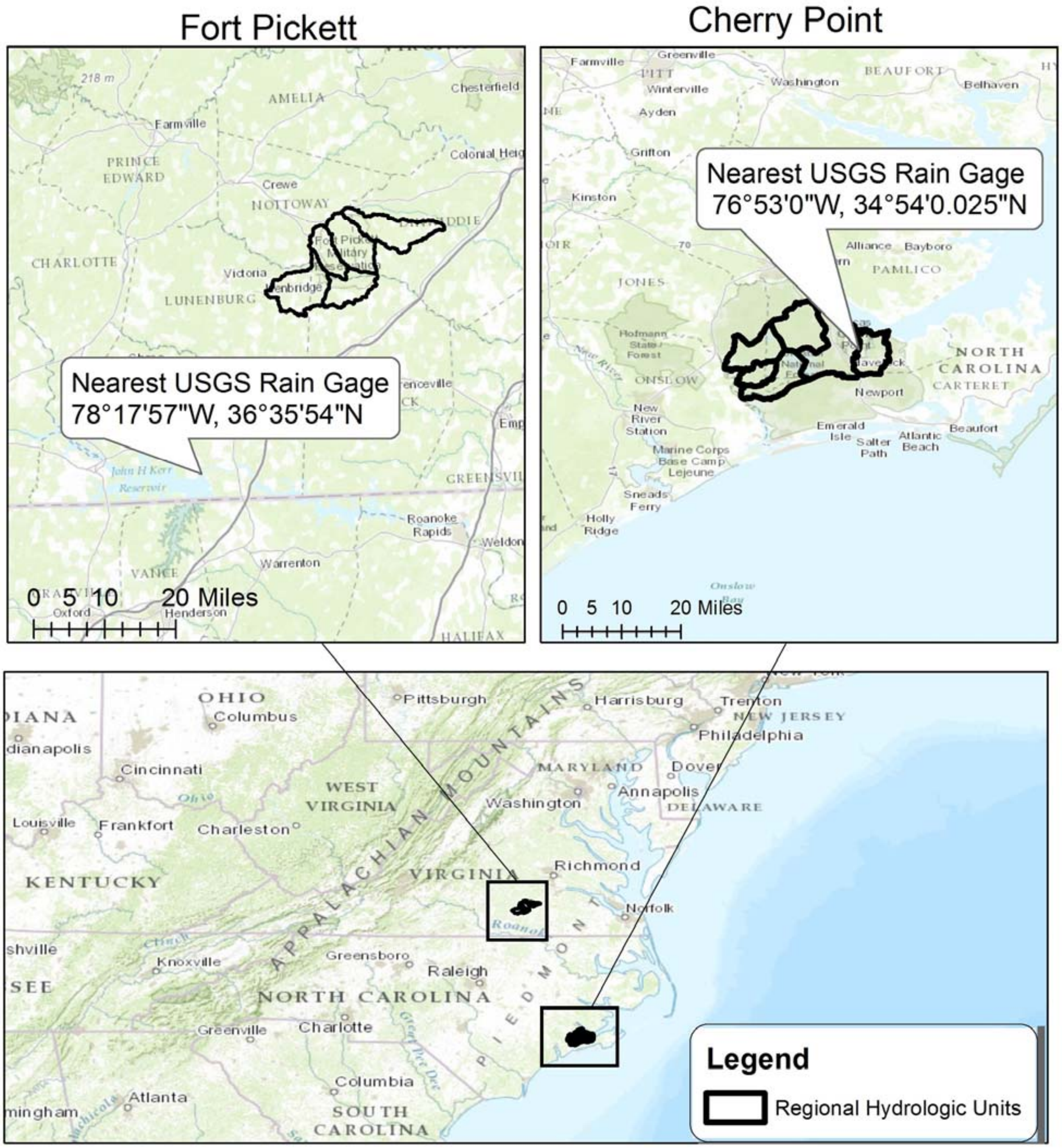
# 6.0 PERFORMANCE ASSESSMENT

We provided an overview of the performance objectives associated with this demonstration in section 3.0. Below, we describe how we assessed performance for each objective.

## 6.1 PERFORMANCE OBJECTIVE # 1: IMPROVE PRODUCTION FUNCTION DETAILS OF GIS-BASED ANALYSIS OF SURFACE WATER REGULATION CAPACITY

This objective is based on the assumption that land cover alone does not reliably predict spatial variation of ES at the installation scale. Improvements in the production function detail were measured by the percentage of calculations incorporated into capacity analysis and mapping. The percentage is calculated by dividing the number of calculation factors for which there was national (presumably lower resolution) and installation (higher resolution) data. The calculation factors were identified in our *capacity* models (see Figures 2 and 3). We emphasize calculation factors instead of data inputs to better reflect the process-based origin of RS. Similarly, we identify ecological demands on ES in the conceptual model because they are used to assess RS flow. As mentioned, we achieved this objective in that all calculation factors were available from national datasets and all but one were available in on-installation data sets. Precipitation was locally monitored only at Cherry Point (Figure 6 top); therefore, we incorporated USGS rain gage data from a site 30 miles from Fort Pickett to serve as a high-resolution dataset (Figure 6 bottom).

**Figure 6: Maps illustrating locations of "installation-level" precipitation gages for Cherry Point (right) and Fort Pickett (left).**



## 6.2 PERFORMANCE OBJECTIVE # 2: IMPROVE PRODUCTION FUNCTION DETAILS OF GIS-BASED ANALYSIS OF SEDIMENT & NITROGEN REGULATION CAPACITY

This objective is analogous to PO #1. There are currently four calculation factors described in the Sediment & Nitrogen Regulation capacity model: precipitation, soil hydrologic groups, land cover, and slope (elevation). All of these were available at high and low resolution, except precipitation, for which no installation data were available at Fort Pickett (see PO #1 and Figure 6 bottom). The finest resolution soil data available was the SSURGO dataset, which is available for most areas in the US. As noted with the surface water regulation model, the source of precipitation data had a notable effect on the results of our models for vertical N retention. As seen in Figure 7, N retention was substantially lower when the 30-year average rainfall data (interpolated from PRISM) was provided as an input. In fact, when using this dataset in the model all relevant hydrologic units (HUs) were on-averge expected to provide little N retention, resulting in a high probability of leaching.

Interestingly, we found substantial differences in model outputs based on the data inputs (30-year average interpolated rainfall data versus recent and local rain gage data). Rainfall-induced runoff was much higher when PRISM 30-year average rainfall data were incorporated into the surface water retention models, compared to local rain gage data (Figure 8). When considering these differences, the preference for data source depends largely on management objectives. The PRISM data included in this analysis reflect 30-year climate norms for the region, whereas the local rain gage data reflect recent annual variability. If the management objective is to look at long-term regional patterns, the PRISM data would be preferable. However, if the objective is to estimate short-term impacts to the delivery of ecosystem services or disservices, the rain gage would be preferable.

**Figure 7: Expected vertical nitrogen retention at Fort Pickett based on (left) 30-year mean daily precipitation (by month) provided by PRISM and (right) mean daily precipitation (by month) calculated from local rain gage data for 2009-2012. The leaching index, from which retention is calculated, includes a seasonality factor that weights the likelihood of leaching based on the proportion of annual rainfall that occurs in the winter, when evapotranspiration is low. Mapped polygons are 12-digit hydrologic units (HUs).**

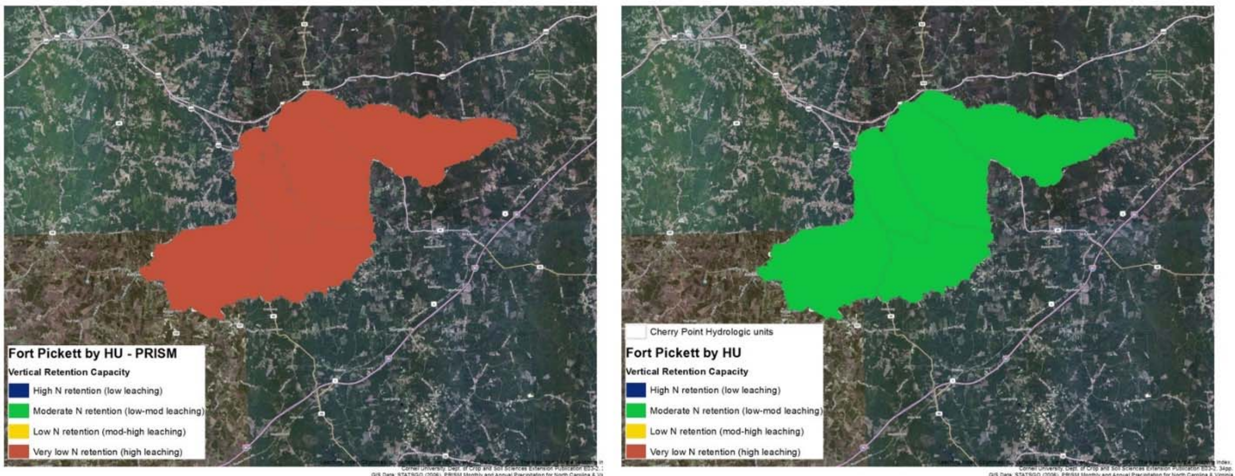
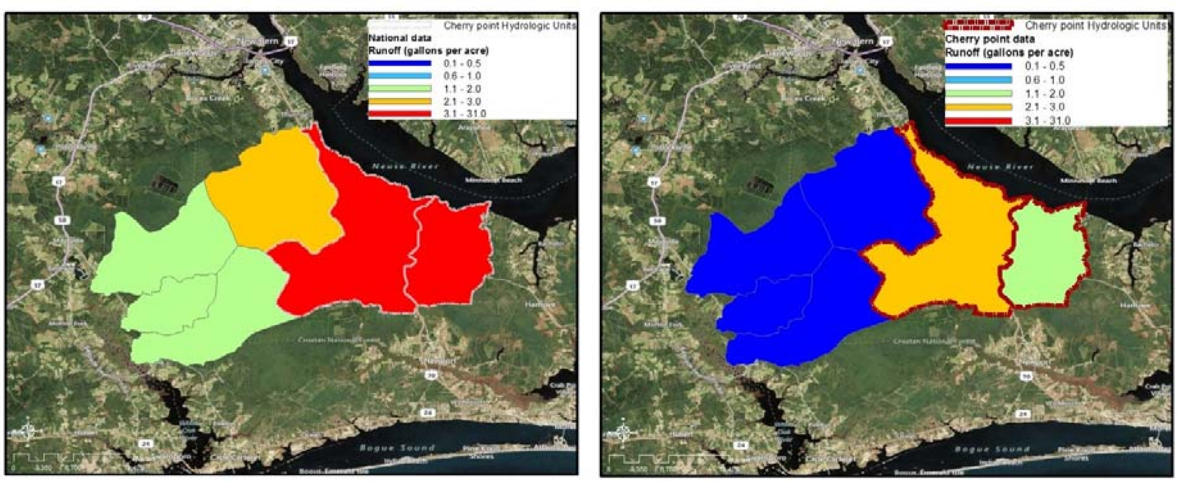



**Figure 8: Expected runoff at Cherry Point based on (left) 30-year mean daily precipitation (by month) provided by PRISM and (right) mean daily precipitation (by month) calculated from local rain gage data for 2009-2012. Mapped polygons are 12-digit hydrologic units.**



## 6.3 PERFORMANCE OBJECTIVE # 3: IMPROVE SPATIAL RESOLUTION OF GIS-BASED ANALYSIS OF SURFACE WATER REGULATION CAPACITY

Although high resolution data are preferable for modeling ES across landscapes, they can require extensive computing power and time. Geospatial models run faster on low resolution datasets. The two models for which computing time may be long are the surface water regulation model and sediment retention model, which are fundamentally linked to the resolution (raster cell size) of land cover and elevation data. Land cover variation appears to be extremely important to capture in these models; however, depending on landscape topography, high-resolution elevation data (10 m or finer) may not be necessary. Elevation was not an input for the surface water regulation capacity model; therefore we judged that a sensitivity analysis would not be informative. Overall, it is important to note that when working with raster datasets, such as digital elevation or land cover derived from satellite imagery, the spatial resolution of model results is constrained by the resolution of the coarsest data set. We developed installation-specific LULC datasets by integrating several vector datasets into a single vector dataset that was converted to raster. We had the opportunity to increase the resolution of this raster LULC dataset; however, given the resolution of soil data provided by the USDA NRCS SURGO dataset, it was not necessary or helpful to increase the resolution beyond 30 m.

## 6.4 PERFORMANCE OBJECTIVE # 4: IMPROVE SPATIAL RESOLUTION OF GIS-BASED ANALYSIS OF SEDIMENT & NITROGEN REGULATION CAPACITY

As mentioned in 6.3, geospatial models run faster on low resolution datasets. To test the sensitivity of the sediment retention model, which relies heavily on elevation and land cover data, we performed a sensitivity analysis of the slope length and steepness (LS) factor to determine whether an input of 10-m elevation data provided substantially different results from an input of 30-m elevation data. We compared the LS results within the relevant HUs for each installation and the time it took our computer to run the model (Table 4). Results suggest that spatial resolution of elevation data has a greater impact on LS factor estimation at Cherry Point, where terrain is relatively flat, than at Fort Pickett. Given the observed difference in mean LS values and the relatively small difference in computing time, using the highest resolution elevation data available seems to be the most cost-effective option.

**Table 4. Effects of elevation data resolution on Length-Slope (LS) factor estimates and computing time.**

| Installation Hydrologic Unit | 10-m Resolution | | 30-m Resolution | |
|---|---|---|---|---|
| | LS Mean | Computing time | LS Mean | Computing time |
| **Cherry Point** | | | | |
| 30203010103 | 8.1 | | 19.4 | |
| 30203010105 | 8.4 | | 19.9 | |
| 30203010202 | 7.5 | 8 Minutes | 18.9 | 6 Minutes |
| 30202040504 | 11.1 | | 19.4 | |
| 30202040303 | 7.4 | | 19.7 | |
| 30202040502 | 9.6 | | 19.4 | |
| **Fort Pickett** | | | | |
| 30102010202 | 19.2 | | 15.9 | |
| 30102010501 | 18.9 | | 15.4 | |
| 30102010204 | 18.4 | 5 Minutes | 14.9 | 3 Minutes |
| 30102010201 | 18.2 | | 15.1 | |
| 30102010203 | 18.8 | | 15.2 | |

## 6.5 PERFORMANCE OBJECTIVE # 5: DEMONSTRATE TRANSFERABILITY OF SURFACE WATER REGULATION SERVICE-RELATED FRAMEWORKS FOR MEASURING CAPACITY, ECOLOGICAL PRESSURE, DEMAND FOR, AND FLOW

We consider our framework to be successful because the data inputs were available for both within and outside of the installations. To gain a regional perspective on ES capacity and ecological pressures, we used our models to map capacity and ecological pressures within the 12-digit HUs that intersected each installation. This included four HUs for Fort Pickett and four HUs for Cherry Point, although two of the latter were within an independent watershed (i.e., they did not flow to or from Cherry Point). We included these independent HUs for a regional reference because there are no hydrologic units that flow into the installation. To run all the models, we combined installation-specific land cover data and precipitation data with national datasets (e.g., NLCD and PRISM) for areas outside of the installation. By creating these seamless layers we were able to run a single model for the installation within the context of its surrounding areas. As mentioned, precipitation was the only data input for which installation-specific data were not available (at Fort Pickett only), therefore we relied on nearby rain gage data. While the combination of the two data sources made it possible to run the ES models for a wider spatial extent, we did notice exceptional variability in the mean estimates of rainfall based

on 30-yr averages from PRISM compared to recent local data (Table 5). These differences were large enough to drive model results, as reported in sections 6.1 and 6.2. These observed differences suggest that using local data, or at least recent data averaged over the long term, provides a more accurate basis for ES analysis.

Mapping the flow of RS as a function of ecological pressure and ambient condition posed the greatest challenge to our ES assessment. Given the noted sensitivity of streams and rivers near our focal installations, we expected both installations to have water quality and flow monitoring stations established. Permanent stream monitoring stations were not established at either installation, and only Fort Pickett had recent water quality data, collected by consultants in 2012. The lack of consistent water quality and flow monitoring prevented us from quantifying the flow of RS in terms of sediment and N loading (see section 6.8). Therefore we concluded that our framework for quantifying the flow of RS depends on ambient condition monitoring and suggest that this aspect of the demonstration be revisited when monitoring data become available.

**Table 5: Precipitation data varied dramatically across sources. PRISM 30-year means (inches [in]) were consistently greater than estimates based on Cherry Point (CP) or local (USGS) rain-gage data collected during the demonstration period.**

| **Cherry Point** | **PRISM** | **CP Rain Gage** |
|---|---|---|
| Annual precipitation | 55-57 in (~14% greater) | 48.8 in |
| Winter precipitation | 23 in (~21% greater) | 18.7 in |
| **Fort Pickett** | **PRISM** | **USGS Rain Gage** |
| Annual precipitation | 45-47 in (~59% greater) | 29.2 in |
| Winter precipitation | 23 in (~77% greater) | 13.2 in |

## 6.6 PERFORMANCE OBJECTIVE # 6: DEMONSTRATE TRANSFERABILITY OF SEDIMENT & NITROGEN REGULATION SERVICE-RELATED FRAMEWORKS FOR MEASURING CAPACITY, DEMAND ON, DEMAND FOR, AND FLOW

The narrative for this PO is shared with PO #5, but applies to the Sediment & Nitrogen Regulation capacity functions. We handled the land cover and precipitation data sets in the same manner explained in 6.5 and the source of precipitation data clearly influenced the results of the vertical N retention model (see 6.2). As noted in 6.5, the lack of ambient condition monitoring was the largest hurdle for the demonstration, which led us to conclude that our framework for quantifying the flow of RS as a function of ecological pressure and ambient condition is not transferable to areas without on-the-ground monitoring of sediment and N concentrations (or alternative measures like water transparency).

## 6.7 PERFORMANCE OBJECTIVE #7: DEMONSTRATE AN ACCURATE FRAMEWORK FOR MEASURING RELATIVE ECOLOGICAL DEMAND ON RS THAT IS LESS FIELD DATA- AND TIME-INTENSIVE THAN FULL-SCALE HYDROLOGICAL MODELING APPROACHES

There are several methods for identifying and mapping ecological pressures. We focused on three methods that vary in terms of field and computer processing intensity. Although we intended to compare these methods for ecological pressures attributed to N, sediment, and surface water pressures (Table 6), we were able to compare all three methods only for sediment loading and surface water, as there were no field-based assessments of N-loading to which we could compare. Observed erosion locations were derived from a 2005 dataset compiled by the Conservation Management Institute (Virginia Tech) and the observed flooding areas were mapped through participation of Cherry Point personnel. We measured the relative difference among these methods by mapping each and quantifying the overlap observed among all three (Table 6). We compared the two methods that incorporate GIS (LULC-based and model-based) to field assessments of pressure that presumably are the most accurate. The LULC-based approach used simple LULC classifications to define a "source" of ecological pressure. This is the easiest and least costly approach of the three. We chose not to run the SWAT model because we learned from site visits that the personnel needed for this level of assessment did not exist. Therefore to make this demonstration more realistic, we developed simpler GIS-based models that require less data than a full hydrologic model but more data than LULC alone. We developed a model and incorporated Curve Number values derived from SWAT model look-up tables. In a similar fashion for sediment retention, we developed a spatially explicit GIS model for predicting erosion based on the Revised Soil Loss Equation and Lim et al. (2005). SPARROW modeling was not conducted for N loading because there were no field estimates of N concentrations with which to compare. Depending on the size of the installation, the model-based approach may be more cost-effective. The model-based approach incorporates the RS capacity models we developed to estimate the expected amount of soil loss and runoff given LULC, soil characteristics, slope, and precipitation patterns.

The results from this comparison are summarized in Table 7 and the spatial overlap among the three methods is illustrated in Figure 9 which provides a map of surface water runoff at Cherry Point and erosion/soil loss from Fort Pickett. As illustrated in Figure 9, there are areas of predicted erosion in excess of field-observed erosion points. In some of the larger areas in the eastern portion of the installation, these high erosion areas are within dudded and high impact zones that are not easily accessible or are completely off-limits. We suspect that erosion monitoring efforts did not include these areas. In this

regard, mapping and modeling areas of expected erosion may provide more cost-effective information for decision-making. In a similar vein, the observations of surface flooding were limited due to the lack of field-based data and observations by installation managers. These observations were limited to impervious surfaces where the flow of stormwater was more likely the issue, rather than the surface ponding and runoff. Based on these results, we concluded that the model-based maps of ecological pressure are more efficient if all model inputs are up-to-date. If geospatial data are out of date, field assessments will be more accurate.

**Table 6: Investment comparison of methodologies for identifying three sources of ecological pressure (nitrogen, sediment, and surface floods). Nitrogen pressure was not included in the comparisons because water quality monitoring that could identify areas of high nitrogen loading does not occur at Cherry Point (CP) and nitrogen loading is not considered an issue at Fort Pickett (FP). Data and model needs for three methods are shown.**

| | **Data and Model Indicators of Regulating Services** | | |
|---|---|---|---|
| **Methods** | **Nitrogen Regulation** | **Sediment Regulation** | **Surface Water Regulation** |
| Least time & data intensive | Upland & Riparian LULC | Upland LULC | Upland LULC & soil types |
| Field & time intensive | Water quality data (CP) | Observed erosion points (FP) | Observed flooded areas (CP) |
| Processing & time intensive | SPARROW model | RUSLE model | NRCS Curve Number Run-off |

**Figure 9: Maps that illustrate the spatial overlap of three methods, which vary in terms of field and computer processing intensity, for identifying and mapping ecological pressures. A) locations of surface flooding reported by Cherry Point personnel (illustrated with green points) overlaying likely sources of flooding based on LULC data, B) locations of surface flooding reported by Cherry Point personnel overlaying flood-prone (high runoff) areas identified by surface water yield (SWY) models, C) locations of erosion reported by Fort Pickett personnel in 2005 (illustrated with green points) overlaying erosion-prone areas identified by models based on LULC data, and D) locations of erosion reported by Fort Pickett personnel in 2005 versus erosion-prone areas identified by soil loss models.**

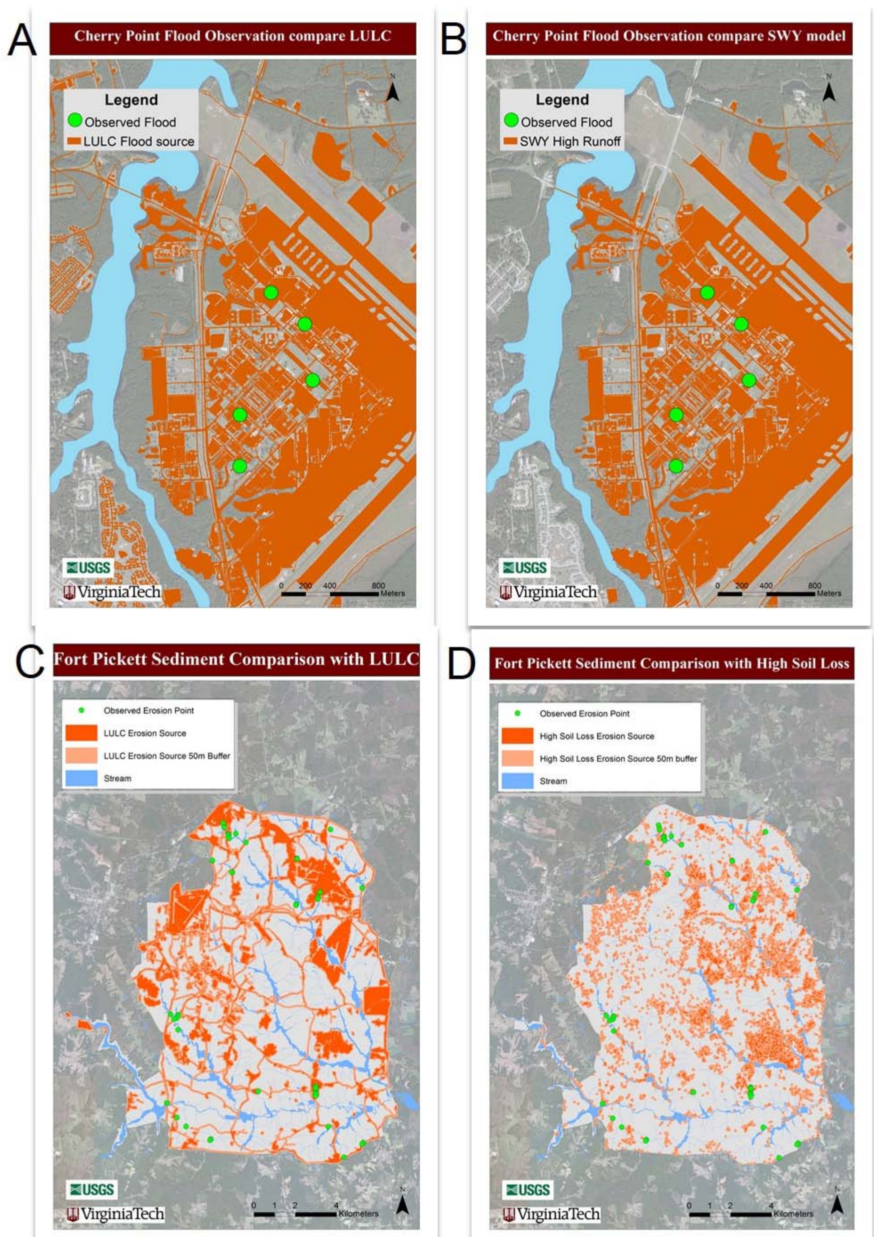


**Table 7: Comparison of ecological-pressure mapping methods. Tabled values are percentages of the observed erosion points (2005) and surface flooding points (2013) that were within LULC-based and model-based predictions of ecological pressure sources. A source is defined as an area from which high soil loss or high surface water runoff is expected.**

| Field observations compared to data/model proxies | | Comparative results |
|---|---|---|
| **Sediment Regulation** (Erosion observation points) | Percentages of erosion points within/near a source defined by LULC | 25% (11/44) of erosion points within a source defined by LULC (unpaved road and developed) |
| | | 75% (33/44) of erosion points within 50 m of a source defined by LULC |
| | | 82% (36/44) of erosion points within 100 m of a source defined by LULC |
| | Percentages of erosion points within/near a source defined by high soil loss (RUSLE model) | 55% (24/44) of erosion points within 50 m of a source defined by high soil loss |
| | | 68% (30/44) of erosion points within 100 m of a source defined by high soil loss |
| **Surface Water Regulation** (Surface flooding observations by installation staff at MCAS Cherry Point) | Percentages of flooding points within a source defined by LULC (high development) | 60% (3/5) of flooding points within a source defined by LULC |
| | | 100% (5/5) of flooding points within 50 m of a source defined by LULC |
| | Percentages of flooding points within/near a source defined by Surface Water Yield (SWY) model | 60% (3/5) of flooding points within a source defined by SWY |
| | | 100% (5/5) of flooding points within 50 m of a source defined by SWY |

## 6.8 PERFORMANCE OBJECTIVE #8: DEMONSTRATE FRAMEWORK FOR MEASURING CURRENT FLOW OF RS IN TERMS OF ECOLOGICAL WORK

We defined RS flow as the ecological work done by the ecosystem to sustain ambient condition despite added stress. For our focal RS, this can be interpreted as the volume of water processed without causing a flood (or drought) and the amount of sediment and N prevented from entering waterways. The goal is to evaluate RS flows based on the processing rather than simply measuring ambient conditions. We reason that areas of high capacity are capable of maintaining conditions at an acceptable level given greater ecological demands on the RS (Figure 4). Due to the lack of field monitoring of ambient water quality at Cherry Point, we focused our

demonstration of PO 8 on sediment loading at Fort Pickett. We defined soil loss from upland areas as the main ecological pressure that would drive the flow of the riparian filtration service. Channel banks may also contribute to sediment loading, but we focused on upland erosion because Fort Pickett aims to maintain 25-m no-activity riparian buffers around all wetland areas (Fort Pickett INRMP) to ensure relatively sound channel stability. This approach provides a watershed-scale snapshot of RS flow quantified as a function of ecological pressure and ambient condition.

Using the water quality monitoring data as the basis of the demonstration, we delineated the contributing area of each monitoring point. We then summarized expected upland erosion (annual tons per acre) for each monitored watershed as the ecological pressure metric. Expected soil loss (annual contaminant input load [ACIL]; Figure 10) and two indicators of sediment pollution, turbidity and total suspended solids (measured annual contaminant load [MACL]; Figure 10), were standardized to range from 0 to 1. We chose to calculate RS flow on a relative scale because the sediment retention model provides an estimate of annual soil loss, while the short-term monitoring data provide merely a snapshot of sediment concentrations. Although these metrics of ecological pressure and ambient condition cannot be readily converted to common units, we expect them to be positively correlated. This expectation enables us to examine indirectly the flow of riparian filtration services.

It warrants noting that we demonstrated this analysis using two disparate sets of field-collected water quality data. The consultants who collected the data and the monitoring sites used differed between studies. The Fort Pickett water quality (FPWQ) assessment established monitoring sites within subbasins located in the installation footprint. In contrast, the Nottoway River water quality assessment established monitoring sites along the river corridor such that each downstream site shared some of the sediment loading influences of sites upstream. In the Nottoway assessment, the size of monitoring basins varied greatly, from 141 to 462 km$^2$, whereas subbasin size varied much less in the FPWQ assessment (1 to 92 km$^2$). Discordance in the design of the two studies precludes an integrative interpretation of our analyses based on them. For example, spatial patterns for turbidity (a metric of ambient condition) are inconsistent between the studies (see panels B and E in Figure 11). Despite the data shortcomings, we used relative measures of ecological pressure and ambient condition to demonstrate the process and analytical outputs whereby RS flow and ecological work can be quantified and mapped.

As suggested conceptually in Figure 10, we subtracted MACL (Figures 11B, 11C, and 11E) from ACIL values (Figures 11A and 11D) for each sampled watershed to provide a relative measure of the flow of riparian filtration services (Figures 12 and 13). Given the nested nature of the monitored subbasins, it is not feasible to estimate an RS flow for each subbasin independently because they overlap. We summarize spatial patterns of calculated RS flow based on relative values of soil loss and mean turbidity in Figure 14.

To test the adequacy of our approach for measuring RS flows, we aimed to conduct a chi-square analysis of expected versus observed values of ecological pressure and ambient condition. Unfortunately, we were unable to do so because field measures of soil erosion, riparian sediment trapping, and in-stream sediment concentrations were not collected on a regular basis. Instead, we prepared a series of maps and graphs that illustrate the observed patterns of RS flow based on relative estimates of annual soil loss and relative measures of in-stream condition. Based on our assessment, only watersheds greater than 200 $km^2$ (i.e., portions of Nottoway River) demonstrated the expected pattern in which relative instream condition measures (based on turbidity) were less than relative measures of soil loss, suggesting RS flow was occurring. This suggests that additional factors are contributing to the observed patterns. For example, bank erosion (not assessed) could greatly influence turbidity and suspended solids at monitoring sites. To fully quantify RS flow, we suggest a) monitoring bank erosion and in-stream sediment concentrations for an entire year, which would provide a more accurate MACL and b) evaluating upland soil loss and filtration capacity along the flow path of eroded soil en route to streams.

**Figure 10: Watershed approach to estimating RS flows based on ecological pressure measured by annual contaminant input load (ACIL) and ambient condition derived from measured annual contaminant load (MACL) at the pour point.**

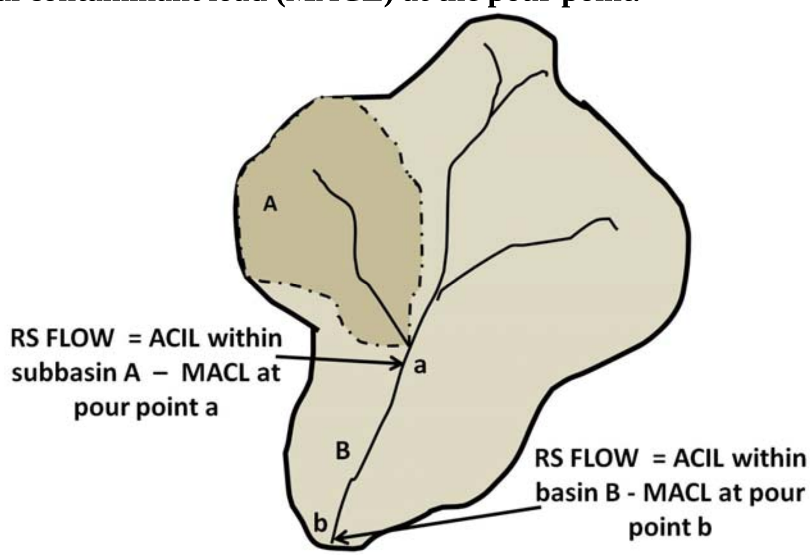


**Figure 11: Water quality (WQ) sampling stations (green flags) and their corresponding catchments in and near Fort Pickett. Two separate monitoring reports, Nottoway River (six sites) and Fort Picket (FPWQ) report (four sites) were conducted prior to this demonstration and the data were used to compare to erosion estimates from within their respective catchments using the RUSLE-based erosion model described in Appendix C6-8. Maps illustrate the: A) Estimated total soil loss (Annual Contaminant Input Load [ACIL in Figure 10]), B) Mean turbidity, C) Mean total suspended solids (TSS), D) Estimated total soil loss (Annual Contaminant Input Load [ACIL in Figure 10]), and E) Mean turbidity for the catchments included in water quality sampling. Measures of turbidity and TSS are from snapshot sampling efforts in Fort Pickett.**

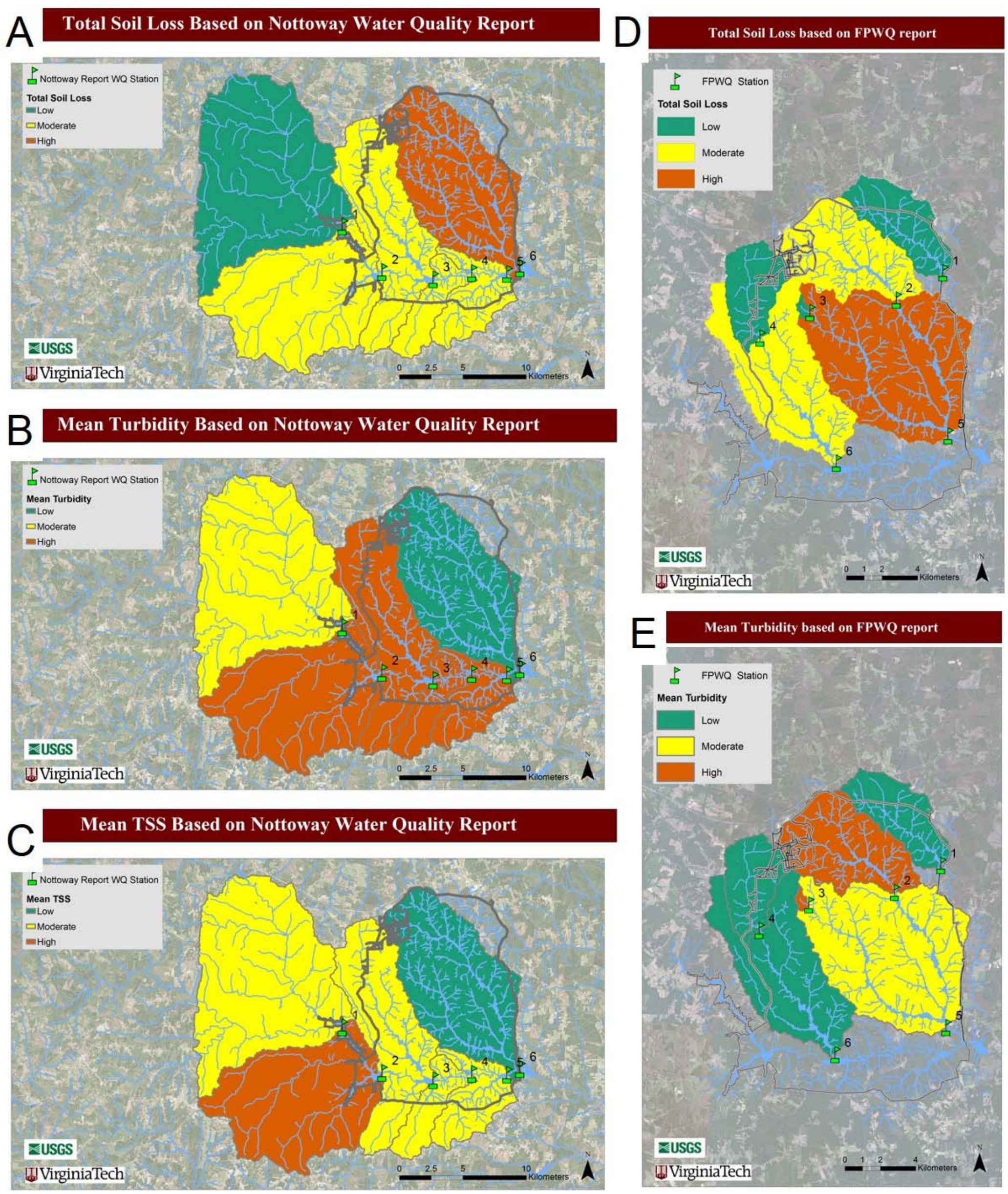


**Figure 12: Relative estimates of regulating service flow are calculated by subtracting relative ambient condition (Mean Turbidity in Figure 11) from relative contribution of ecological pressure (Total Soil Loss in Figure 11). These values are mapped for each Fort Pickett watershed sampled for water quality in 2009, based on a Fort Pickett Water Quality report (FPWQ).**

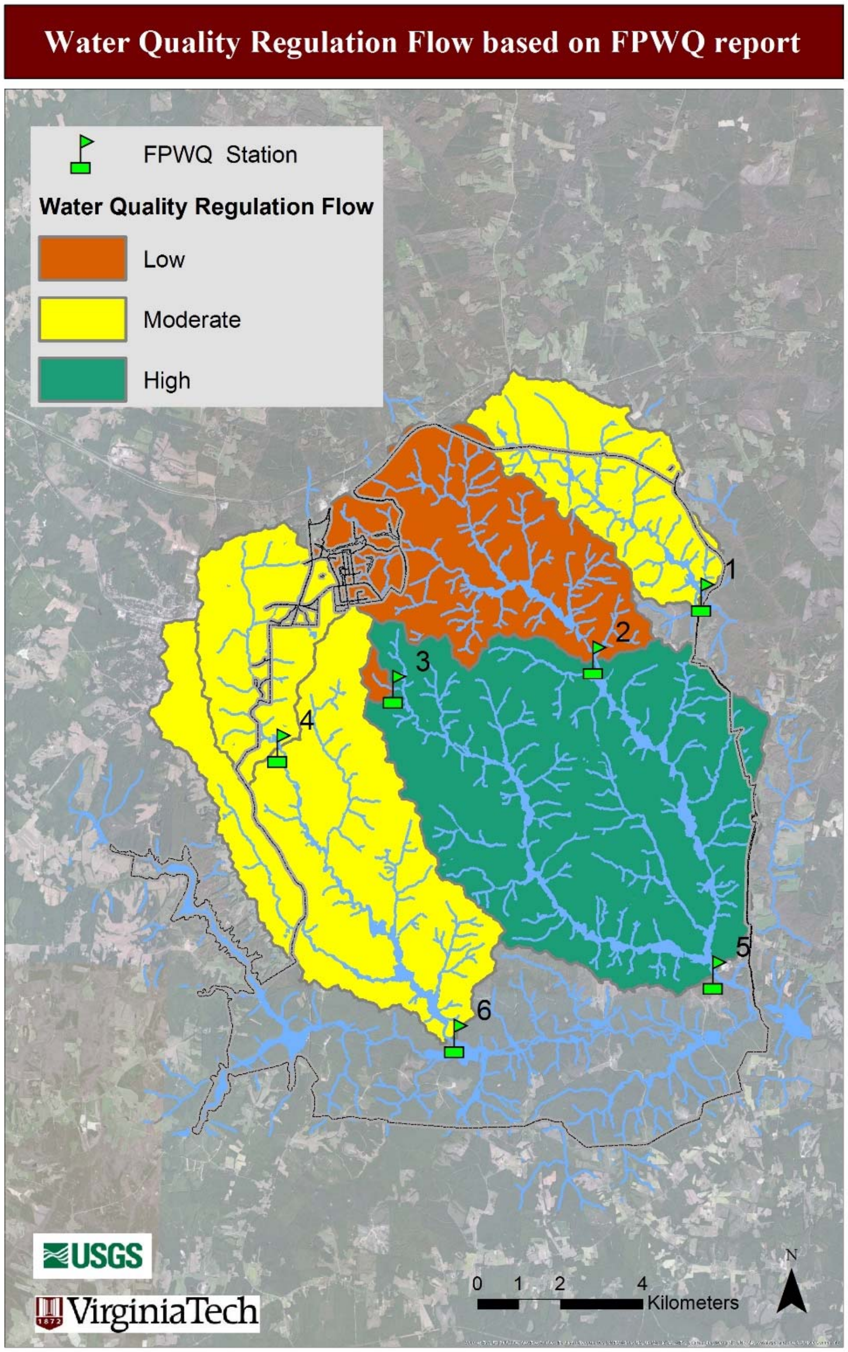
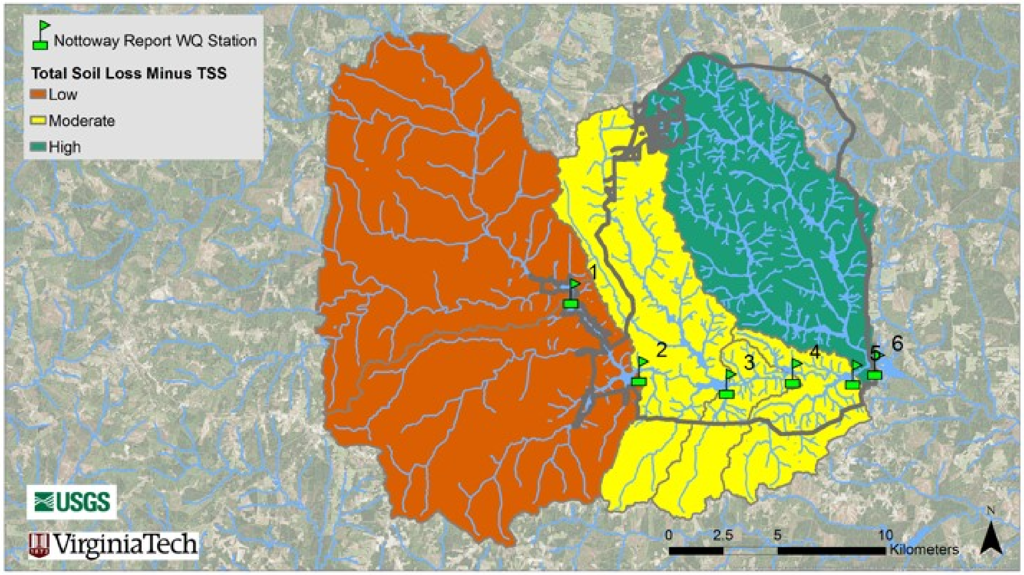


**Figure 13: Relative estimates of regulating service flow are calculated by subtracting relative ambient condition (Mean Turbidity or Mean Total Suspended Solids [TSS] in Figure 11) from relative contribution of ecological pressure (Total Soil Loss in Figure 11). These values are plotted for six Nottoway River sites where water quality (WQ) was monitored. The relative ecological work conducted by riparian filtration within each 12-digit hydrologic unit impacted by Fort Pickett is illustrated in the map.**

**Water Quality Regulation Flow Based on Nottoway Water Quality Report**




**Water Quality Regulation Flow Based on Nottoway Water Quality Report**

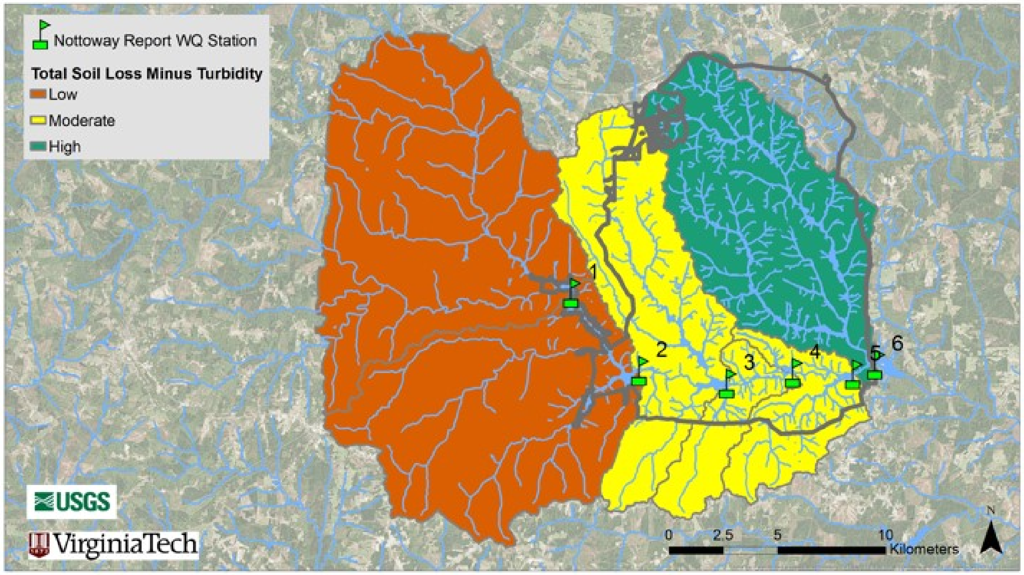
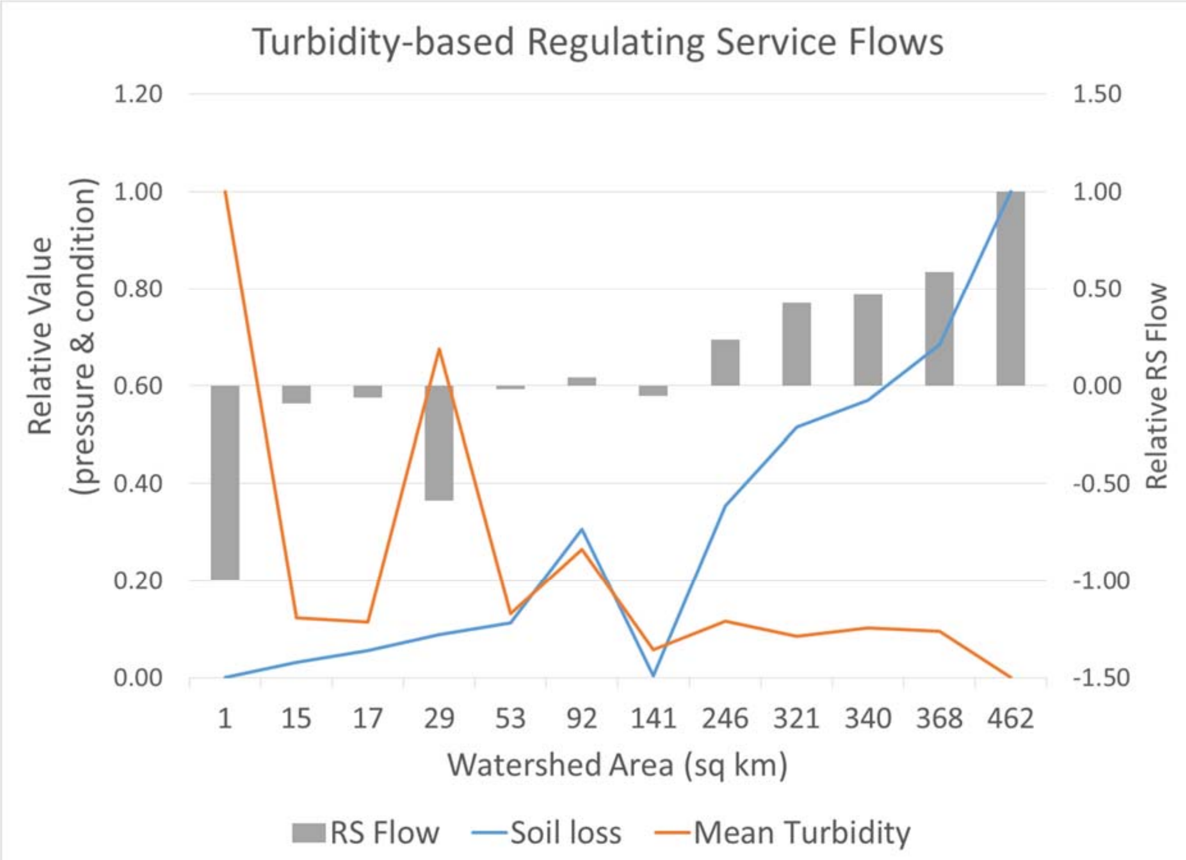


**Figure 14: Relative values of total soil loss (ecological pressure) and in-stream turbidity (ambient condition) are plotted for 12 Nottoway River and Fort Pickett Water Quality Monitoring sites. Riparian filtration service (RS) flow is graphed on the secondary y-axis (on right) as the relative difference between soil loss and turbidity (i.e., ecological work).**




## 6.8 PERFORMANCE OBJECTIVE # 8 REVISED

Given the difficulty in demonstrating the practice of calculating RS flow in terms of ecological work, we added a component that demonstrated how the geographic flows of services and disservices could be mapped (Figures 15 and 16). This process identifies service benefit and disservice zones based on recognized sources of RS provision and ecological pressure, respectively. We demonstrate the use of this tool by identifying areas with a high probability of contributing eroded soil to streams and mapping the potential transport of sediment to streams. The specific area where sediment could enter surface waters is referred to as the critical riparian area (CRA). We suggested that a reasonable measure of success would be to map the flow of services and pressures from training areas on each installation and create a framework that prioritizes compatible buffer land parcels impacted by on-installation land use and ES. We were successful and created two reference maps for each installation that highlight sources of ecological pressure and map the hydrologic-based flow of these pressures (eroded soil and

surface water runoff). Likewise, a comprehensive prioritization framework was created in tabular form to evaluate how installation-buffer lands contribute to RS flows to and from installations.

**Figure 15: Critical riparian areas, identified by mapping surface water flow-paths, represent specific locations through which riparian filtration services flow.**

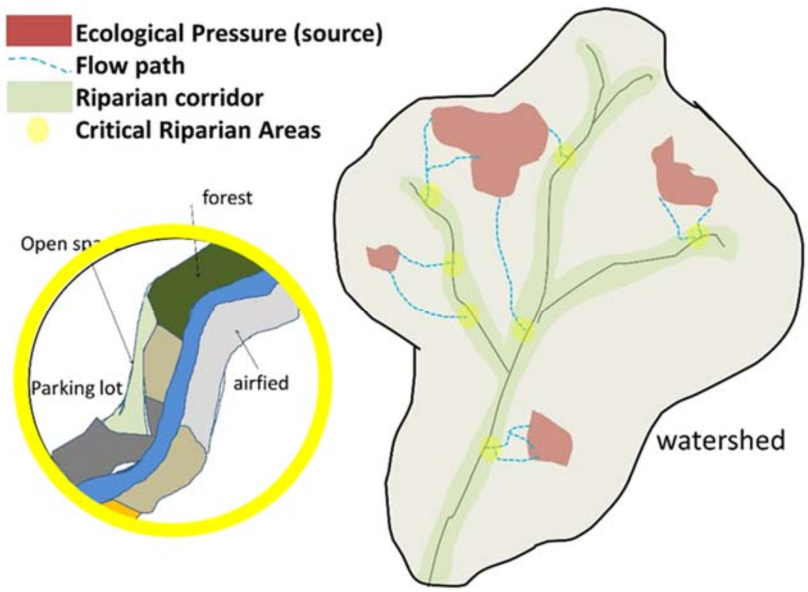
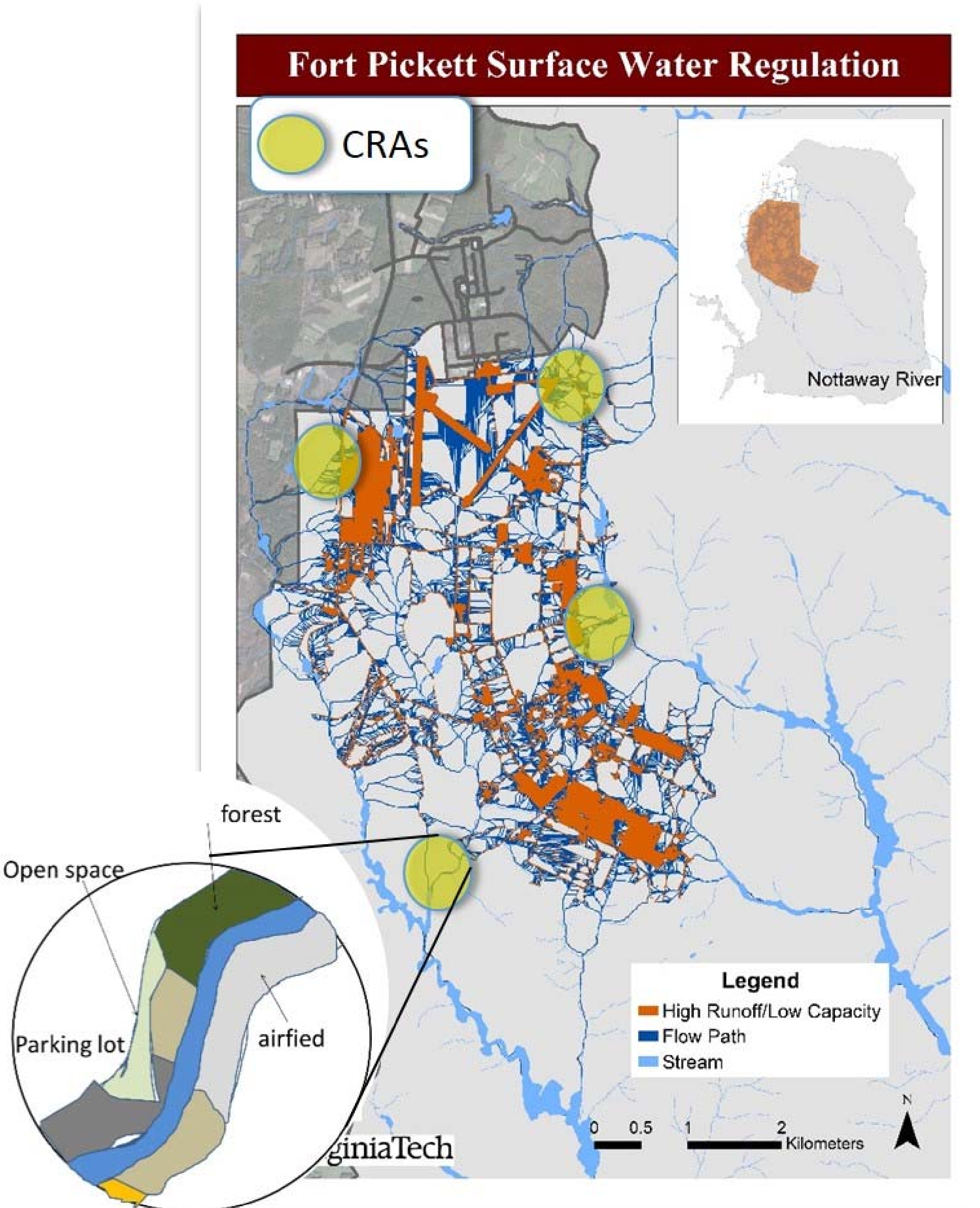


**Figure 16: Map of critical riparian areas (CRAs) based on water flow (along flow-paths) from areas of high surface runoff potential.**



## 6.9 PERFORMANCE OBJECTIVE # 9: DEMONSTRATE MINIMAL PROPAGATION ERROR IN GEOSPATIAL DATA

Errors in geospatial data can be attributed to several sources. Within a given dataset, errors may be spatial (e.g., the boundaries are inaccurate) or attributed to misclassification (e.g., classed as a wetland when it is really a forest) (Alesheikh et al. 1990). Although not a dataset error, the accuracy of a given dataset is subject to changes over time. LULC is particularly dynamic over time; as time passes the accuracy of a LULC dataset has an increasing probability of being incorrect. Similar changes could occur to soils over time, but this is less common. Since the RS models we used rely on several other datasets in addition to LULC, we found that incorporating data-producer accuracy (%) associated with each land-cover class was extremely challenging and not particularly useful because it did not account for the errors we noted during field validation. Field validations at both installations suggested that the geospatial data we were working with were out of date, which resulted in low user accuracy (Table 8). Common mis-classifications were clearly attributable to ecological succession (e.g., barren to grassland) or development (e.g., grassland to developed).

We used a stratified, random selection technique to identify field validation sites. Site selection was stratified by LULC type and the number of sites of each stratum reflected the proportional LULC within the installation (Appendix D). Field site visits were conducted within 1-2 days during which we visited the selected validation sites and recorded the current LULC class. The results from the LULC validations are provided in Table 8. A full matrix of inaccuracies is provided in Appendix D. The User and Producer Accuracies of the LULC dataset that we compiled based on installation data was less accurate then national assessments of NLCD data (2001 and 2006) for most LULC classes (Wickham et al. 2010, 2013). In particular, accuracy of installation classifications of forests and wetlands were much lower than published accuracies for the NLCD. We suspect this can be attributed to a) the mosaic approach we took to compile LULC data rather than basing our LULC shapefile on satellite imagery and b) the dated GIS data that was provided to us during the demonstration. It was difficult to maintain an updated database during the transition of GIS analysts from Fort Pickett and data sharing was difficult throughout the project. We were not aware of an updated GIS dataset until we visited the installations in 2014 to present our final results. Given this high level of uncertainty with our compiled LULC dataset and the NLCD, we recommend incorporating local LULC data, especially for wetlands, in composite LULC data and validating and updating annually to ensure accuracy and minimize model propagation error.

This experience suggests that individual installations and regional DoD GIS working groups might consider taking an adaptive management approach to data acquisition, management, and updating to ensure that important data users have access to up-to-date data.

**Table 8: User accuracy of land use - land cover (LULC) data synthesized from Fort Pickett and Cherry Point GIS data.**

| Presumed LULC class | Number of sites sampled | User accuracy | Common LULC class observed in the field |
|---|---|---|---|
| **Fort Pickett** | | | |
| Forest (deciduous, coniferous, mixed) | 25 | 53, 55, 67% | Shrub, grassland |
| Wetland | 5 | 17% | forest |
| Developed (high) | 4 | 50% | forest, barren |
| **Cherry Point** | | | |
| Forest (deciduous, coniferous, mixed) | 12 | 0%* | shrub, forest |
| Wetland | 5 | 0% | forest |
| Developed | 9 | 0%** | forest |

***** Specific forest classifications were 0% accurate, but within collective forest classes (deciduous forest, evergreen forest, and mixed forest) there was 0-86% accuracy.
** 100% of presumed open space pixels were observed to be high development.

We focus our synthesis on forest, wetland, and development LULC classes because these are the most prominent classes on installations and because they have strong influences on RS capacity. For example, developed land may filter out 5-35% of N in surface waters whereas riparian forest cover may be able to filter out 72%. Our results suggest that (i) our interpretation of a wetland is different from that of installation personnel or that the antecedent condition was unusually low during our field validation, (ii) forests have either been disturbed since the most recent land cover data were collected (Cherry Point) or succeeded the shrublands previously mapped (Fort Pickett), and (iii) the extent of developed land observed on the ground is variable, depending on the orientation of green space and the sample point. Given the direction of the most common misclassifications (Table 8), we suggest that our estimates of RS capacity are underestimates. Forest, shrub and wetland support higher capacities of riparian filtration, surface water regulation, and sediment regulation; the N leaching model is not affected by land cover, so ground water protection is not impacted by inaccuracies in land cover.

## 6.10 PERFORMANCE OBJECTIVE #10: ENHANCE ES-BASED DECISION SUPPORT SYSTEMS

We were highly successful at developing GIS tools and ArcScripts and produced two or three tools to quantify the capacity of each RS (Appendix C). The data inputs for each of these models

were either provided to the installation directly, or a tool was developed so analysts can prepare the input themselves. The latter strategy was used for data inputs that will change over time (e.g., mean winter precipitation in Figure 4). Tools were designed so that GIS beginners could operate the models. All tools are transparent in that the models upon which they are based are also provided so GIS experts can modify as needed. In addition to the model-based tools and compilation of important data inputs, we also designed an End-User-Guide (EUG) that will help future users navigate the tools and their outputs. The EUG, relevant data, and ArcTools were provided to appropriate staff at Cherry Point and Fort Pickett during our final presentation site visit.

## 6.11 PERFORMANCE OBJECTIVE #11: DEMONSTRATE UTILITY OF A FRAMEWORK FOR INTEGRATING RS INTO NATURAL RESOURCE AND MISSION PLANNING DECISIONS

We used questionnaires, distributed to installation staff likely to use our framework or tools, to assess success in this objective. Questionnaires were distributed immediately after our end-of-project presentations of findings at each installation (8-9 July 2014 for Cherry Point; 30 October 2014 for Fort Pickett). We initially planned to stratify staff into planners and decision-makers versus GIS analysts and natural resource managers for survey purposes. However, two factors led to our pooling of all respondents within each installation: small sample sizes and the preference of most respondents to remain anonymous. Thus, our analysis of survey responses is based on the same group of respondents for all questions, although not every respondent answered every question. Our findings are based on one respondent from Cherry Point and seven respondents from Fort Pickett.

We assessed ease-of-use of our framework and tools by surveying installation staff expected to use the framework and/or tools at the conclusion of the demonstration. To assess ease-of-use, we developed two survey questions, each with a 3-level score (3 is best; 1 is worst). We received two responses from Cherry Point and eight responses from Fort Pickett across the two questions on ease-of-use; mean scores were 3.0 and 2.5, respectively (Table 9). Survey results indicate that our demonstrated framework and GIS tools were generally adequate and easy to use.

We assessed the utility of our framework for integrating RS into natural resource and mission planning by surveying installation staff expected to use the framework and/or tools at the conclusion of the demonstration**.** To assess utility, we developed six questions, each with a 3-level score (3 is best; 1 is worst). We received six responses from Cherry Point and 41 responses from Fort Pickett across the six questions on RS utility; mean scores were 3.0 and 2.6, respectively (Table 9). Survey results indicate that the demonstrated framework and can be useful in environmental compliance and land use planning.

We also assessed our effectiveness in advancing installation staff's knowledge of ES delivery in the end-of-project survey by developing five questions, each with a 3-level score (3 is best; 1 is worst). We received five responses from Cherry Point and 35 responses from Fort Pickett across the six questions on ES knowledge; mean scores were 3.0 and 2.5, respectively (Table 9). Survey results indicate that staff likely to use our framework and/or tools adequately understand the conceptual basis for analyzing ES delivery related to their installation.

**Table 9: Summary of survey responses from installation staff likely to use our ES framework and/or tools. Respondents assigned a 1 (worst), 2, or 3 (best) to each performance aspect. CP = Cherry Point; FP = Fort Pickett. The number of responses was calculated as the total number of survey responses rather than the number of respondents since the number of survey questions pertaining to each performance aspect was different and not all survey participants responded to all questions. The questionnaire is shown in Appendix E.**

| | Mean Response | | Range of Responses | | Number of Responses | | Relevant Survey Questions |
|---|---|---|---|---|---|---|---|
| Performance aspects | CP | FP | CP | FP | CP | FP | |
| Ease of using demonstrated framework and tools | 3.0 | 2.5 | 3-3 | 2-3 | 2 | 8 | 9,10 |
| Utility of ecosystem-service concepts and framework | 3.0 | 2.6 | 3-3 | 2-3 | 6 | 41 | 8, 12, 13, 14, 15, 17 |
| Advances in ecosystem-service knowledge via the demonstration | 3.0 | 2.5 | 3-3 | 2-3 | 5 | 35 | 1, 2, 3, 4, 16 |
| Utility of scenario analysis | 3.0 | 2.3 | 3-3 | 1-3 | 4 | 28 | 5, 6, 7, 18 |
| Engagement of demonstration team with installation staff | 2.8 | 2.2 | 2-3 | 2-3 | 5 | 26 | 11, 19, 20, 21, 22 |

## 6.12 PERFORMANCE OBJECTIVE #12: IMPROVE PROJECTIONS OF REGULATING SERVICES

This objective was based on our belief that projections can be improved and better informed by including the decision-makers in the development of future scenarios. We held a half-day scenario planning workshop at each installation during which we met collectively and individually with key players in installation environmental management and mission operations (at Fort Pickett only). During our meeting we discussed the most important issues facing the installation and listed the types of information needed to make informed planning decisions. Personnel at both installations were highly concerned with suburban encroachment and their image within surrounding communities. We discussed the services (e.g. wildlife habitat provision and recreation opportunities) that the installations provided and compared those to the potential disservices or ecological pressures that were attributable to the installation (e.g., sediment loading into the Nottoway River). To address this concern, the participants at both installations referred to their respective compatible-use land conservation programs – ACUB at Fort Pickett and EP at Cherry Point. Through discussion with participants we arrived at a scenario of interest that involved prioritizing future ACUB and EP land acquisition to maximize RS capacity associated with installations and to minimize the disservices conveyed from installations to neighboring communities. Based on this input, we developed a prioritization framework that (*i*) evaluated the capacity of focal RS within each land parcel proposed for the ACUB and EP programs, (*ii*) determined whether the land parcel would contribute services/disservices to the installation or be a recipient of services/disservices, and for Fort Pickett, (*iii*) determined whether the potential ACUB land could reduce surface water runoff and help reduce sediment loading (by means of filtration) into the Nottoway River. These metrics were calculated on a relative scale (0-1) for all potential land parcels and summed to determine a final rank. Parcels with greater RS capacity that intersected a disservice flow from the installation to stream were given the highest priority rank. If the parcel intercepted flow from Fort Pickett into the Nottoway River it was ranked higher than those associated with other contributing streams.

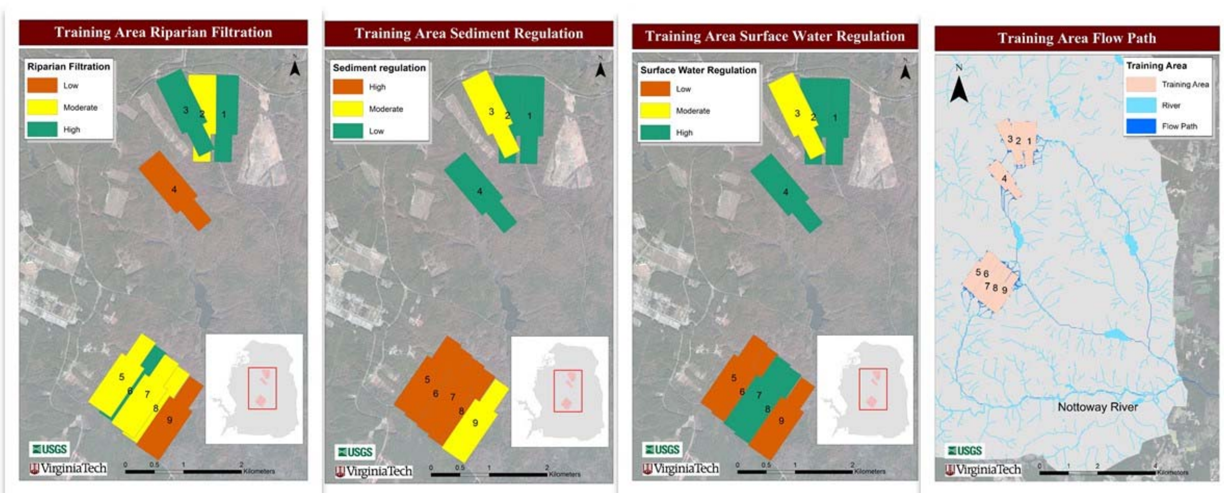
We assessed usefulness of workshops by surveying workshop participants. Our analysis of survey responses is based on the same group of respondents described for Performance Objective #11 (above). We developed four questions, each with a 3-level score (3 is best; 1 is worst). We received four responses from Cherry Point and 28 responses from Fort Pickett across the four questions on the value of scenarios; mean scores were 3.0 and 2.3, respectively (Table 9). Survey results indicate that the scenario workshops and analytical products are generally helpful in environmental compliance and land use planning.

## 6.13 RANGE SITING COMPARISON

In collaboration with the RC-201113 team, we conducted a post-hoc analysis of ES capacity change expected with the development of new training ranges on Fort Pickett. The potential sites for new ranges were determined by the RC-201113 team and shared with us for analysis with our

RS toolset. To begin, we calculated baseline RS capacity for all sites and used these values as the basis for our assessment and prioritization (Figure 17). The RC-201113 team assessed biodiversity, carbon storage and sediment export impacts from the development of new training ranges (Figure 18, middle). We assessed potential impacts to riparian filtration, erosion control, and surface water regulation (Figure 18, top). Given the lack of overlap in the particular services that were mapped by both teams, we can provide little insight into which analytical approach is more credible or cost-effective. The Natural Capital team estimated sediment retention and filtration as one metric, whereas we evaluated these separately to reflect the upland and riparian components of minimizing sediment loading into surface waters. We suggest that our more compartmentalized approach is better suited to informing on-the-ground management decisions about preventing upland erosion or stabilizing sediment along riparian corridors and stream banks.

**Figure 17: Baseline comparison of riparian filtration (left), erosion control/sediment retention (middle left), surface water regulation capacity (middle right) and the hydrologic flow-paths of (dis)services (right) from each of nine potential new training ranges.**




Impacts were assessed by calculating baseline ES capacity, calculating the relative change that would occur with conversion of the site to grassland (Daily et al. 2014), calculating the percentage change from baseline, and then normalizing the change on a scale of 0 to 1 (Figure 18). The normalized changes for each ES at each site were summed in each of the team-specific studies (Table 10), assuming equal weights for each service, then site priority ranks were assigned based on these sums. Given that RC-201113 and RC-201114 teams both focused on sediment loss, but used different methods, we also provide a summary ranking in which the normalized loss values are averaged to avoid biasing the final ranks by an emphasis on erosion. Notably, we assumed equal weights among services to enable us to compare results with the RC-

201113 team; however, summary rankings could readily be altered to reflect installation priorities and values.

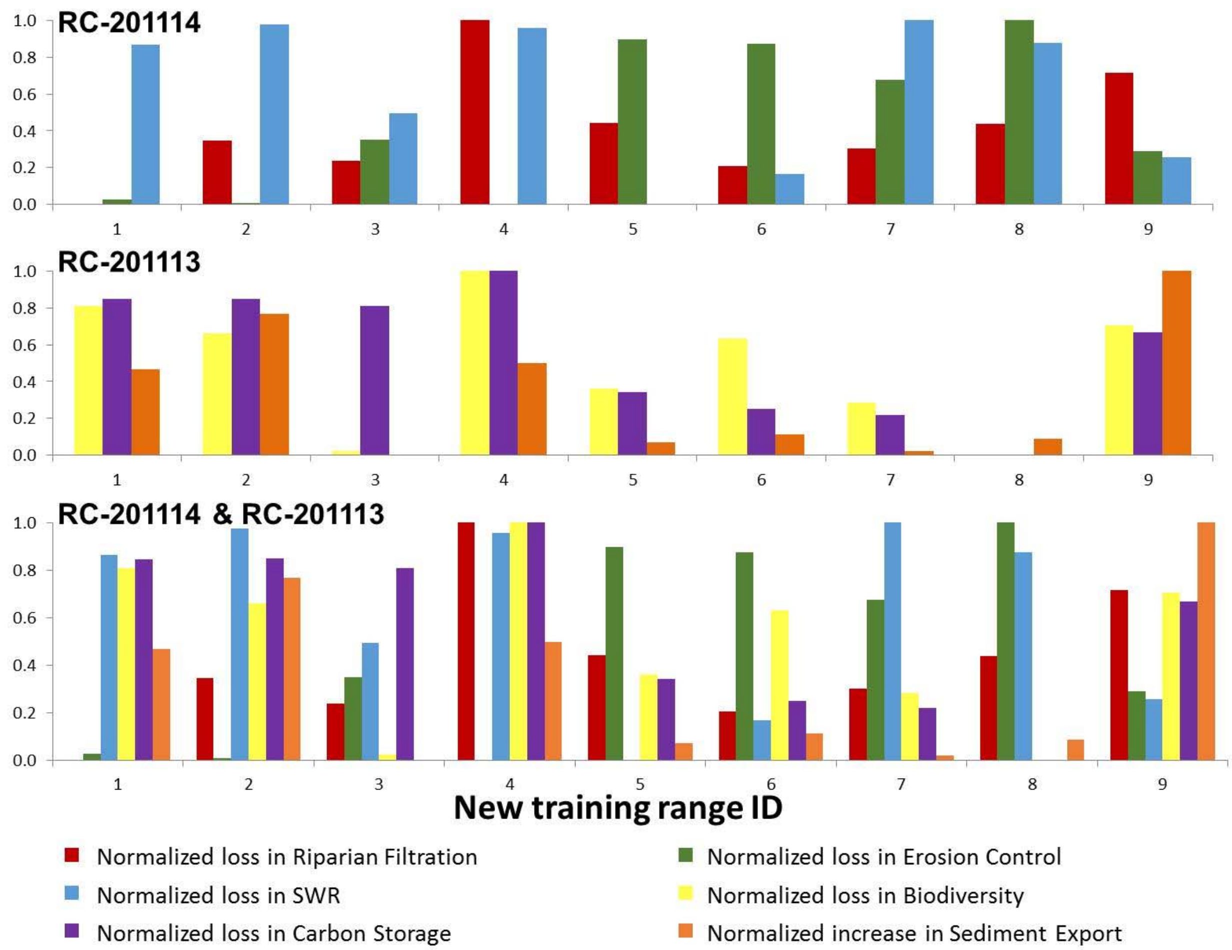
Our analysis shows that likely effects of developing a new training range vary greatly across potential sites, with little correlation between the sets of services analyzed by the two teams (Table 10). In other words, there is no single best site to develop to minimize impacts on all ES analyzed. Nor is there agreement between the two summary rankings. Rather, choosing a site will require planners to weigh tradeoffs among specific ES associated with converting land cover. Such tradeoffs may be less pronounced if other arrays of ES or sites are analyzed. In any case, the new tools we developed to analyze impacts on ES can be used to examine explicitly the various tradeoffs associated with making land-use decisions on military installations.

**Table 10. Ranks of potential new training areas at Fort Picket with respect to effects on six ecosystem services. Lower values represent sites that are preferable because they minimize loss of ecosystem service capacity. The two most preferred sites are noted in bold for each column. The right-most column provides a site ranking based on five services in which sediment regulation reflects the mean rank assigned by distinct methods of demonstration projects led by Villamagna and Angermeier (this report) and by Daily et al. (2014).**

| Training area | Rank for biodiversity, carbon storage, sediment export | Rank for riparian filtration, erosion control, surface water regulation | Summary rank for all six services | Summary rank for five services* |
|---|---|---|---|---|
| **1** | 6 | **1** | 6 | 7 |
| **2** | 7 | 5 | 7 | 8 |
| **3** | 4 | **2** | **1** | 5 |
| **4** | 9 | 7 | 9 | 9 |
| **5** | 3 | 6 | **2** | **2** |
| **6** | 5 | 3 | 3 | **1** |
| **7** | **2** | 8 | 5 | 4 |
| **8** | **1** | 9 | 4 | 3 |
| **9** | 8 | 4 | 8 | 6 |

* Includes biodiversity support, carbon storage, riparian filtration, surface water regulation, and a combined soil erosion and export metric based on the mean ranking of sediment export and erosion control.

**Figure 18: Normalized losses of ecosystem service capacity from the development of new training ranges (1-9) on Fort Pickett, VA (USA). Top: Riparian filtration, erosion control, and surface water regulation (SWR) results from the RC-201114 team. Middle: Biodiversity, carbon storage, and sediment export results from the RC-201113 team. Bottom: Summary (two upper panels combined) of losses associated with developing new training ranges.**



## 7.0 COST ASSESSMENT

## 7.1 COST MODEL

Costs associated with this demonstration include effort (i.e., labor), equipment, data storage, software licenses, and geospatial and non-spatial data. Each is described in Table 11. We do not expect costs to be affected by life-cycle issues or the frequency of anticipated use of our proposed approach.

**Table 11: Cost model for ecosystem service assessment methodology.**

| Cost Element | Data Tracked during Demonstration | Estimated Costs |
|---|---|---|
| **Computer workstation** | Estimates based on the optimal computer processor for reducing processing time and maximizing memory and mapping resolution | $1400-$1600 |
| **ArcGIS license** | Estimates based on the cost to installations and term of license | Sunk cost |
| **Geospatial data inputs** | Estimates based on the costs of data compilation from data repositories | $0 |
| **Field data collection** | Estimates based on time needed to conduct field validation for each geospatial data input and mean labor cost | $600-$1200, depending on the sampling protocol |
| **Analyst effort** | Estimates based on time needed to gather, prepare, and process data inputs in ArcGIS by GIS analyst | $500 (@ $25/hr for one week) per capacity tool analysis |

- **Computer workstation:** A computer will be needed to collate, prepare, and process data and to map ES. Desktops with > 10 GB rapid access memory (RAM) perform best and will ultimately decrease processing time. We estimated the cost of an optimal desktop computer for our analyses at the on-set and end of the demonstration and the percentage decrease in cost annually.
- **ArcGIS license:** ArcGIS is a one-time cost that is already paid for and possessed by all DoD installations.
- **Geospatial data inputs:** The data required to assess ES on installations was free, although we do suggest an increase in field validation and updating of GIS data.
- **Field data collection:** To demonstrate the accuracy of our approach, we collected field data on land cover. Such data validation costs would ordinarily be distributed across other uses of spatial data. Because we aimed to minimize field costs, we tracked the time and labor costs

for our field data collection and suggest a range for other installations depending on their size and landscape heterogeneity.

- **Analyst effort:** We estimated analyst effort in units of the time it takes to collate, prepare, and process data and to map ES, given the availability of ArcTools or ArcScripts. We assumed that the analyst is familiar with the data inputs and basic ArcGIS processing, including ArcTools and ArcScripts.

## 7.2 COST DRIVERS

The main cost drivers that potentially impact the use of the models and tools we developed include a) purchase cost of a high performance GIS computer with suitable RAM and disk space, and b) salary of a GIS analyst. The cost of a high performance GIS workstation continues to decrease over time, but the needs for a faster processor and greater RAM continue to increase as the software (ESRI ArcGIS) evolves. Based on our experience in this project, an on-base GIS analyst serves a wide array of managers and decision-makers, which means that cost is shared across multiple mission objectives. Therefore, the cost for a GIS analyst to implement the models and tools demonstrated herein largely depend on the overall role and responsibilities of the GIS analyst on installation. We discuss cost alternatives for this in section 7.3 below.

## 7.3 COST ANALYSIS AND COMPARISON

If ES assessment frameworks are to be adopted by installations, it could be helpful to have one person, such as a Regional GIS Analyst, who would use the models and tools described herein to serve all installations within a specified region. This could increase efficiency and consistency among installations since data could be gathered and applied systematically. It also could reduce the time investment in learning and adapting the models, as well as the purchase and maintenance cost of a GIS workstation. Under this design, the field validation of sites could be conducted via partnerships with installation-specific GIS analysts and field technicians, with guidance from the regional GIS Analyst. This structure also may ensure that all installations apply the same sampling protocol and report producer and user accuracy in the same way. Finally, organizing these analyses regionally might promote partnerships to collect data outside installation boundaries (e.g., to document encroachment patterns) and enhance the economies of scale for investment in remote sensing (e.g., LiDAR).

From a more comprehensive perspective, we suggest that three components of our demonstration – the RS capacity framework for prioritizing buffer lands around military installations, the critical riparian area analysis, and the training area scenario analyses – have potential to significantly reduce the costs of land use planning and compliance. While we cannot provide specific estimates of cost savings because RS are not currently included in planning or decision-making, feedback from managers suggests that the frameworks and methods we presented would

provide a common ground and new currency for evaluating decisions and expressing trade-offs. Having explicit information for a variety of scenarios would avoid the cost of re-planning and therefore help achieve training and stewardship objectives more cost-effectively.

## 8.0 IMPLEMENTATION ISSUES

This demonstration was largely focused on applying RS capacity, ecological pressure, and spatial flow models to answer questions related to potential land use decisions. To facilitate the implementation of these RS evaluation methods, we developed a suite of geodatabases that contain input data, toolboxes, and ArcMap documents that relate to focal RS or preprocessing objectives (e.g., land use change). The methods for mapping and quantifying RS are applied in a spatially explicit environment within ArcGIS and the methods are provided in two forms: a model-based form in which all inputs, intermediate products and processes are editable and an ArcTool form in which the interface simply prompts data inputs and the naming of model products. During our final presentation to Cherry Point, we met with key GIS personnel to demonstrate the use of the tools and organization of the data. We incorporated their feedback into the final preparation of data. In addition to the data being organized around the focal RS, we have prepared an EUG that explains the objective of each tool/model and describes the input data and model output. The EUG contains screenshots of the models to help the user understand the embedded processes. We developed the EUG so that anyone with moderate training in ArcGIS and ArcTool can conduct the analyses we demonstrated.

We know of no regulations that would limit the use of our methodology for assessing RS in or near military installations. However, installations might review their data security protocols to see if the transfer of needed spatial data could be made more expedient. Our methodology incorporates software and data downloaded from widely available sources, which may present some security risks. If ES assessment frameworks are adopted by installations, it may be helpful to review protocols that balance data security with access to relevant spatial data and software.

Maintenance of, and access to, adequate GIS and ES expertise is a potential implementation issue. Timely implementation of our methodology requires a GIS analyst to be familiar with relevant spatial data and models, as well as the ES concepts underpinning their use. The use of our methodology presumes moderate training in ArcGIS and ArcTool but also requires some additional training with the methodology itself (e.g., via the EUG). Thus, if ES assessment frameworks are adopted by installations, they could assess if their staff had appropriate training and consider options for providing and maintaining that training. Potential options might include taking short-courses or consulting with off-installation experts. It may also be helpful to review protocols related to attracting, retaining, and refilling GIS expertise at installations. Finally, given that neighboring installations may share needs for GIS expertise, a related factor to consider is whether it is more cost-effective to distribute the needed expertise locally at individual installations versus regionally at centralized locations.

A second potential implementation issue is availability of appropriate data. We encountered hurdles related to data from on-installation water quality and field condition monitoring (i.e., ambient environmental quality). Our experience on both installations drew attention to the need

for more systematic monitoring and assessment programs, especially for environmental metrics (e.g., nutrient concentrations in surface water, fine-sediment levels in streams) closely tied to key compliance issues. Further, such data need to be collected at appropriate spatial and temporal resolutions to inform management questions. In particular, storm water and soil erosion are major environmental concerns at Cherry Point and Fort Pickett, respectively. Our methodology could help inform environmental assessments and decisions but appropriate data are crucial. In particular, field-collected data on ambient conditions are needed for validating models, providing accurate model inputs, and ultimately documenting progress toward management goals. During our demonstrations, we were unable to identify well-suited datasets on water quality at either installation. Thus, if ES assessment frameworks are adopted by installations, they could assess if the amount of locally and/or regionally collected data is adequate to address key questions germane to environmental management and compliance. If appropriate data are lacking, it may be helpful to review the priorities assigned to installation-specific environmental monitoring.

In this context, two alternatives seem worth considering based on our experience at Fort Pickett and Cherry Point. First, it may be possible to establish partnerships with state agencies and/or nearby stakeholders to share costs and data for water quality monitoring. Second, a potential alternative for evaluating the applicability of our methodology is to conduct analyses similar to those presented in section 6.8 on other installations that have routine water quality and field site assessments of erosion. Given the data available to us, we tried to demonstrate clearly how this information would be used to quantify the *flow* of regulating services in terms of ecological work on installations. Such a quantification would enhance the power of our hydrologic flow-path models to map and evaluate beneficiaries of (dis)services originating from installations.

A third potential implementation issue is how to provide sufficient engagement with ES experts so that installation personnel can recognize opportunities to use ES analyses to address environmental concerns. Our discussions with installation staff regarding how our methodology could specifically be applied or what changes (by us *or* them) might make its application more effective were quite limited, mostly occurring near the end of our demonstrations. For example, our final presentation at Cherry Point revealed an interest in using our source-flow tools to evaluate the potential downstream impacts of changes in on-installation land use. Incorporating these methods for evaluating downstream impacts was considered valuable to future NEPA compliance documentation, but our ability to demonstrate the tools explicitly in that context was limited because the July 2014 meeting was the first time this interest was mentioned (despite labored conversations about scenario analysis in March 2013).

During our demonstrations, we saw clear links between ES and mission issues such as environmental compliance, land use planning, and suburban encroachment but our interactions with installation staff may have been too brief and disjointed to make those links clear enough to them for our work to seem relevant or timely. An alternative approach, given staff's general unfamiliarity with ES, might have been to focus the demonstrations on resolving a specific

environmental issue by applying an ES-based approach, but without first laying out ES concepts for staff, then asking them to come up with ways that approach can be useful. The focal issue (e.g., suburban encroachment) might have been identified from the get-go via a region-wide assessment rather than via installation-specific discussions. If ES assessment frameworks are adopted by installations, it may be helpful to occasionally reach out to regional ES experts to seek guidance on how to frame environmental concerns in ways amenable to ES analyses.

At the start of the demonstration, there was serious concern among installation personnel about the amount of time our demonstration would take from their already limited schedules. In response to this concern, we tried diligently to limit communication and meetings to those in which multiple objectives could be met. For example, our first meeting was designed to introduce installation personnel to ES and the types of analyses possible, as well as gather GIS data. The second meeting was to present baseline maps of focal RS and to meet with personnel to develop helpful scenarios for RS analysis. The third and final meeting was designed to present the results of the scenario analysis, to demonstrate additional applications of the methods and models developed, and to gather feedback about the demonstration. In retrospect, we would move the scenario analysis to earlier in the demonstration to ensure we had ample time to explore the potential applications that arose after we presented the full demonstration results.

A final potential implementation factor, which could amplify all the issues mentioned above, is that installation personnel are very busy. Personnel may not embrace new tools or methodologies if the utility of those tools/methodologies is not properly conveyed or if personnel are not provided ample training with, or time to implement, them. Thus, if ES assessment frameworks are adopted by installations, it may be helpful to plan for additional training so that personnel become adequately informed regarding the utility and application of such assessments.

In summary, we foresee few future issues, especially technological constraints, limiting the implementation of the demonstrated framework for using regulating services to evaluate ecological resilience. The GIS tools we developed can be used within the Arc GIS 10.2 environment and require no further licenses beyond those already owned. We have developed our end products, along with an EUG that will enable GIS analysts to conduct the same analyses described in this report as well as adapt and update the underlying models as needed (through Python scripting or in Model Builder). The tools demonstrated in this project were developed to facilitate assessment of baseline and future changes to the landscapes of specific installations and surrounding areas. However, with such assessments comes the need for a) accurate information that drives the specification of model parameters and b) time for staff to conduct the analyses. We found that on-installation personnel time was the most limited resource, followed by on-the-ground data from water quality monitoring; both limited the success of our demonstration. Implementation of our methodology may lead to re-assessments of the tradeoffs installations make in prioritizing their limited resources for environmental management. Even so, our work shows that implementing an RS-based assessment framework and methodology can provide

insight into future land management on military installations, including decisions related to encroachment buffers, stewardship, and regulatory compliance.

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**APPENDICES**

**Appendix A: Points of Contact**

| POINT OF CONTACT<br>Name | ORGANIZATION<br>Name<br>Address | Phone<br>Fax<br>E-mail | Role in Project |
|---|---|---|---|
| Ken Oristaglio | Natural Resources Manager, Fort Pickett, Blackstone, VA | Phone: 434-298-6416<br>Email: kenneth.l.oristaglio.nfg@mail.mil | Point of contact for project development, meeting organization, and non-GIS data transfer |
| Colin Johnson | GIS Analyst/Manager, Fort Pickett, Blackstone, VA | (no longer at Fort Pickett) | GIS analyst and temporary manager of ACUB program |
| Carmen Lombardo | Natural/Cultural Resources Manager, MCAS Cherry Point, North Carolina | Phone: 252-466-5870<br>Email: carmen.lombardo@usmc.mil | Point of contact for project development and input for scenario analysis |
| Jessica Guilianelli | NEPA Compliance Specialist, MCAS Cherry Point | Email: jessica.guilianelli@usmc.mil | Installation liaison that assisted with meeting organization and initial data transfer |

## Appendix B: Data Sources

Description of data used to calculate capacity of and ecological pressure on focal regulating services (RS), ambient condition, and capacity calculation factors for RS. Acronyms are listed on pages ii-iii. 'NA' = not applicable.

| RS | Purpose | Data Description | Source | Resolution | Extent | Year |
|---|---|---|---|---|---|---|
| **Sediment & nitrogen regulation** | Capacity for RS | Land use / cover | National Land Cover Database (NLCD) | 30m | National | 2006 |
| | | | USDA NASS Cropland | 30m | National | 2010 |
| | | | Installation-specific data | <30m | Fort Pickett & Cherry Point | unknown |
| | | Annual/monthly/daily precipitation | PRISM (1971-2000) | 800m | National | Mean 1971-2000 |
| | | | PRISM monthly data | 4000m | National | 2010-2011 |
| | | | USGS rain gauges | Point data | National | Real-time |
| | | Elevation | USGS National Elevation Dataset | 3m, 10m , and 30m | National | 2009 |
| | | | Installation-specific elevation data | 2m (Fort Pickett); (Cherry Point) | Fort Pickett & Cherry Point | |
| | | Soil characteristics | USDA SSURGO | Vector - polygon | National | 2005 |
| | Ambient condition | Surface water monitoring | USGS, VADEQ, NCDWQ, USEPA | Vector - point data | National | Real-time |
| | | Impaired waters (303d list) | USEPA | Vector - line data | National | 2010 |

| Sediment & nitrogen regulation | Purpose | Data Description | Source | Resolution | Extent | Year |
|---|---|---|---|---|---|---|
| | Demand for RS | Human population census 2000 | US Census Bureau, US Bureau of Labor Statistics | Census tract | National | 2010 |
| | Demand on RS | Sewage discharge points | NC Rural Economic Development Center | Point data | North Carolina | 2000 |
| | | Swine lagoons | NC Center for Geographic Information and Analysis | Point data | North Carolina | 2003 |
| | | Animal operation permits | NC Center for Geographic Information and Analysis | Point data | North Carolina | 2003 |
| | | Impervious surfaces (percent) | NLCD | 30m | National | 2006 |
| | | Annual/monthly/daily precipitation | PRISM monthly data | 4000m | National | 2010-2011 |
| | | | USGS rain gauges | Point data | National | Real-time |
| | Capacity calculation factor | Vertical retention capacity | New York Nitrate Leaching Index- Percolation Equations for Soil Hydrologic Groups[1] | Vector and raster data | NA | 2003 |
| | | Horizontal retention capacity | USDA – Revised Universal Soil Loss Equation (RUSLE2) [2] | Vector and raster data | NA | 2008 |
| | | Surface filtration capacity | Land cover within 50m of surface waters. Removal efficiencies (%) suggested by Mayer (2007) | Vector raster Land cover data | NA | 2005 |
| | | Uptake and volatilization | Unknown | | | |
| **Surface water regulation** | Capacity for RS | Land use / cover | National Land Cover Database | 30m | National | 2006 |
| | | | USDA NASS Cropland | 30m | National | 2010 |
| | | | Installation-specific data | <30m | Fort Pickett & Cherry Point | |

| | Purpose | Data Description | Source | Resolution | Extent | Year |
|---|---|---|---|---|---|---|
| **Surface water regulation** | | Annual/monthly/daily precipitation | PRISM (1971-2000) | 800m | National | Mean 1971-2000 |
| | | | PRISM monthly data | 4000m | National | 2010-2011 |
| | | | USGS rain gauges | Point data | National | Real-time |
| | | Elevation | USGS National Elevation Dataset | 3m, 10m , and 30m | National | 2009 |
| | | | Installation-specific elevation data | 2m (Fort Pickett); (Cherry Point) | Fort Pickett & Cherry Point | |
| | | Wetlands | National Wetlands Inventory | Vector data | National | 2011 |
| | | Soil characteristics | USDA SSURGO | Vector - polygon | National | 2005 |
| | | Hydrologic Units and subbasins | USGS National Hydrography Dataset | Vector – polygon and Vector-line data | National | 2005 |
| | | Dams | USACE | Vector – point data | National | 2004 |
| | Ambient condition | Stream flow volume | USGS National Water Information System | Vector – point data | National | Real-time |
| | | Stream flow velocity | USGS National Water Information System | Vector – point data | National | Real-time |
| | | Stream depth | USGS National Water Information System | Vector – point data | National | Real-time |
| | Demand on RS | Annual/monthly/daily precipitation | PRISM monthly data | 4000m | National | 2010-2011 |
| | | | USGS rain gauges | Point data | National | Real-time |
| | | Impervious surfaces (%) | NLCD | 30m | National | 2006 |

| | Purpose | Data Description | Source | Resolution | Extent | Year |
|---|---|---|---|---|---|---|
| **Surface water regulation** | Demand for RS | Human population census | US Census Bureau, US Bureau of Labor Statistics | Census tract | National | 2010 |
| | Capacity calculation factor | Infiltration | New York Nitrate Leaching Index- Percolation Equations for Soil Hydrologic Groups [1] | Vector and raster data | NA | 2003 |
| | | Runoff | NRCS Curve Number Runoff Estimation Method [3] | Vector and raster data | NA | 1972 |
| | | Evapotranspiration | NRCS Curve Number Runoff Estimation Method [3] | Vector and raster data | NA | 1972 |

[1] New York Nitrate Leaching Index = Percolation Index (PI) * Seasonal Index (SI) where Seasonal Index (SI) = $[2P_w/P_a]^{1/3}$

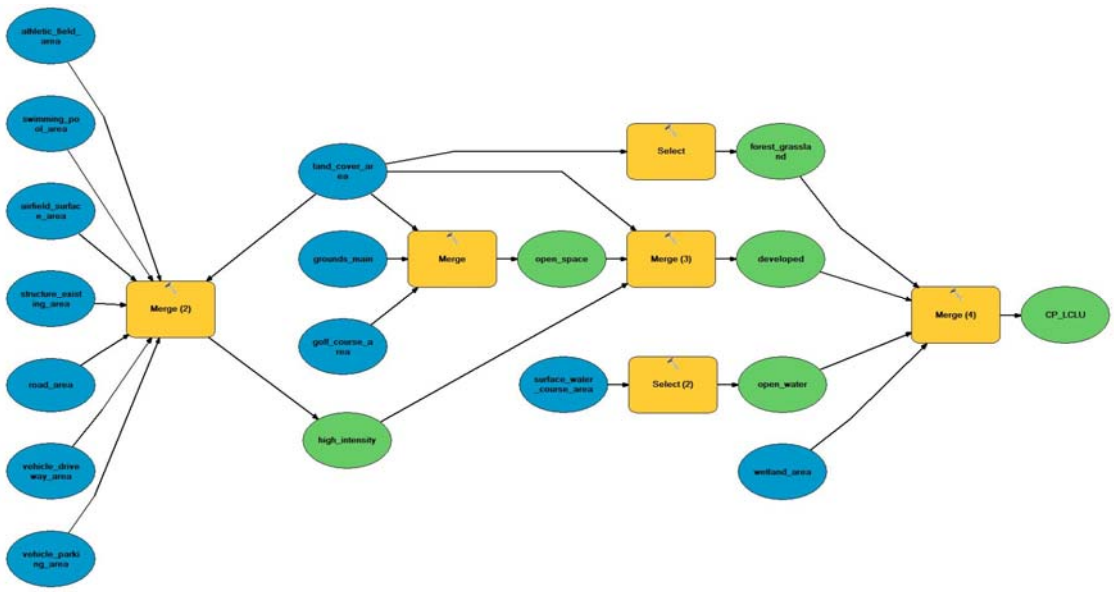
[3] NRCS Curve Number $$\text{Runoff Volume} = \frac{(P_a - 0.2S)^2}{(P_a - 0.2S) + S}, \text{ where storage (S)} = \frac{25{,}400}{\text{CurveNumber - 254}}$$ (NRCS 1972)

[2] Revised Universal Soil Loss Equation (RUSLE) A = R * K * LS * C * P, where R = rainfall-runoff erosivity factor, K = soil erodibility factor, L = slope length factor, S = slope steepness factor, C = cover-management factor, and P = support practice factor

## Appendix C: Models and ArcTools Developed during Demonstration

**Figure C1: A) Conceptual model illustrating the data inputs (blue), geospatial tools (yellow) and outputs (green) created to produce a single LULC shapefile from seven existing, but separate, LULC data sets. B) ArcTool interface where the user can browse to enter data inputs and define the location of the final output "land use land cover output".**

A)




B)

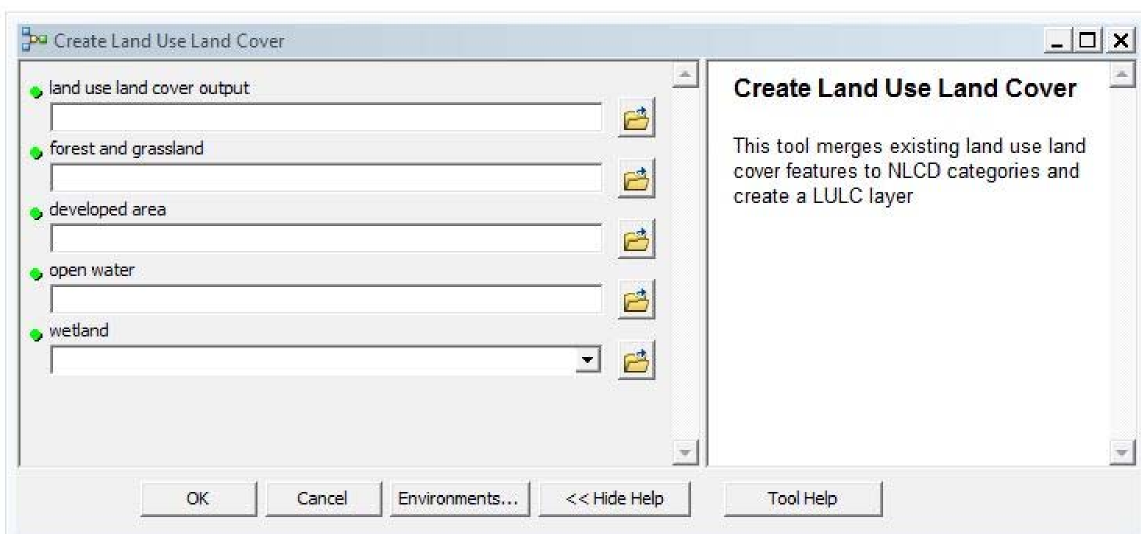


**Figure C2: A) Conceptual model illustrating the data inputs (blue), geospatial tools (yellow) and outputs (green) created within the surface water runoff model that was created based on the NRCS Curve Number Runoff equation. B) ArcTool interface where the user can browse to enter data inputs and define the location of the final output that estimates runoff for each unique hydrologic response unit.**

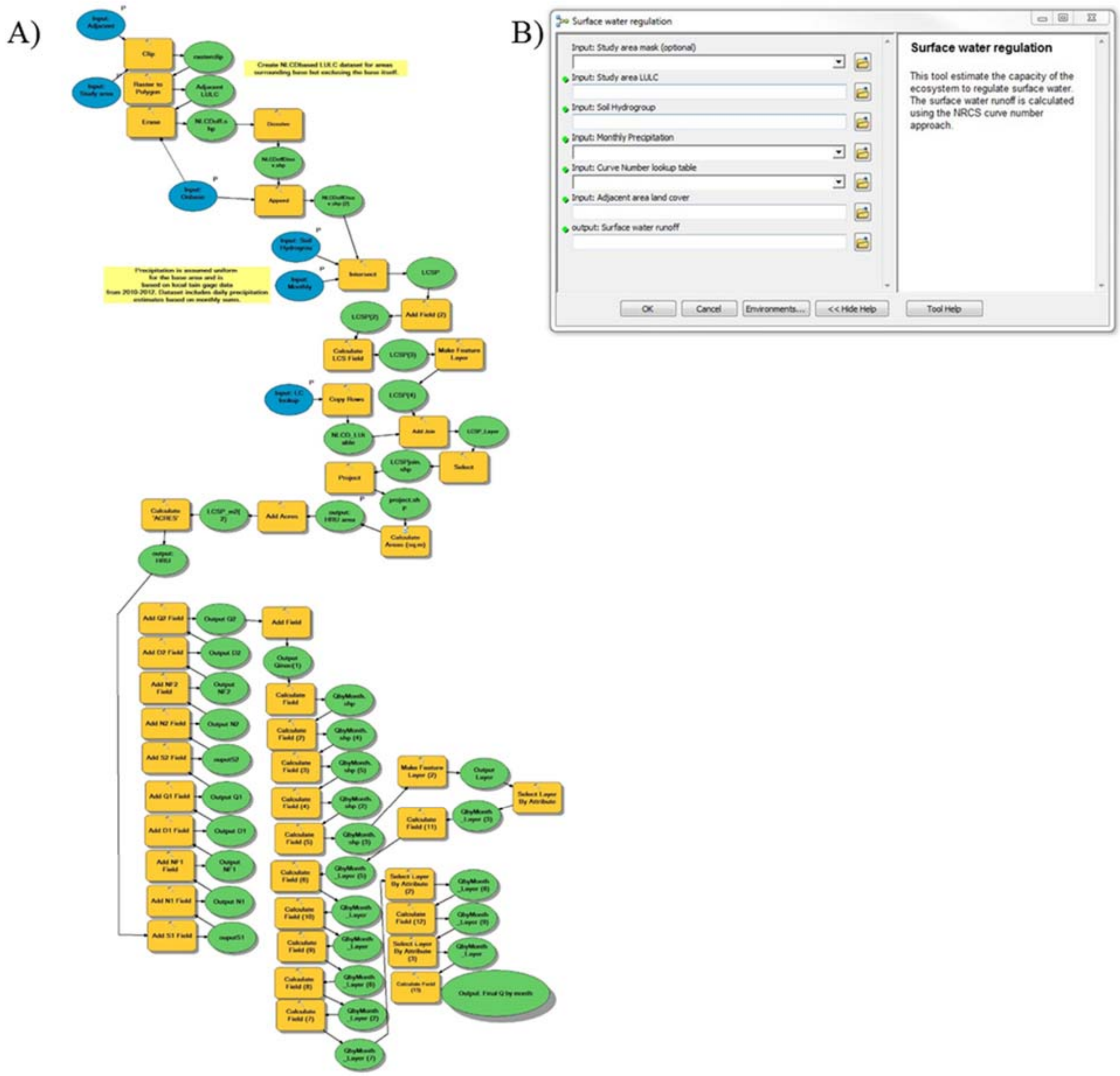
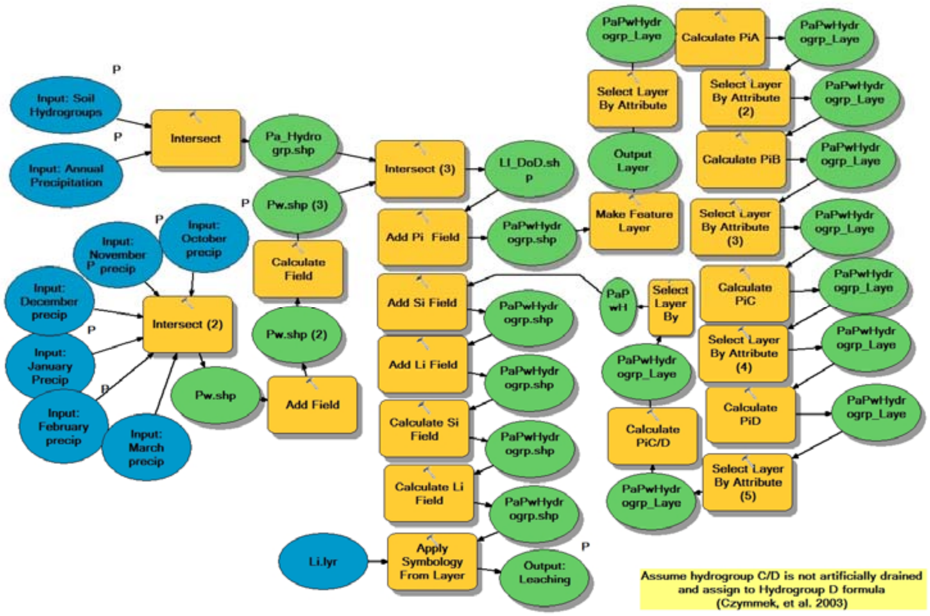


**Figure C3: A) Conceptual model illustrating the data inputs (blue), geospatial tools (yellow) and outputs (green) created within the vertical nitrogen retention model that was based on the New York Nitrate Leaching Index equation. B) ArcTool interface where the user can browse to enter data inputs and define the location of the final output that calculates the leaching index value for each unique hydrologic response unit.**

A)




B)

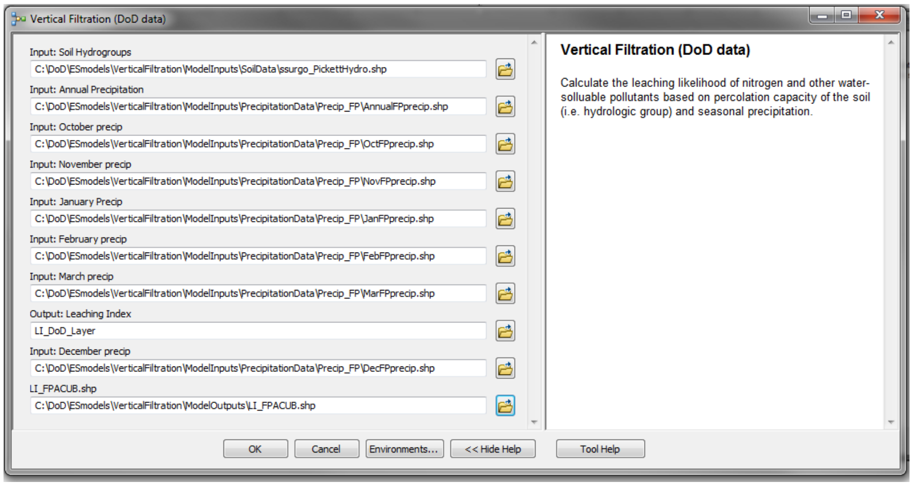
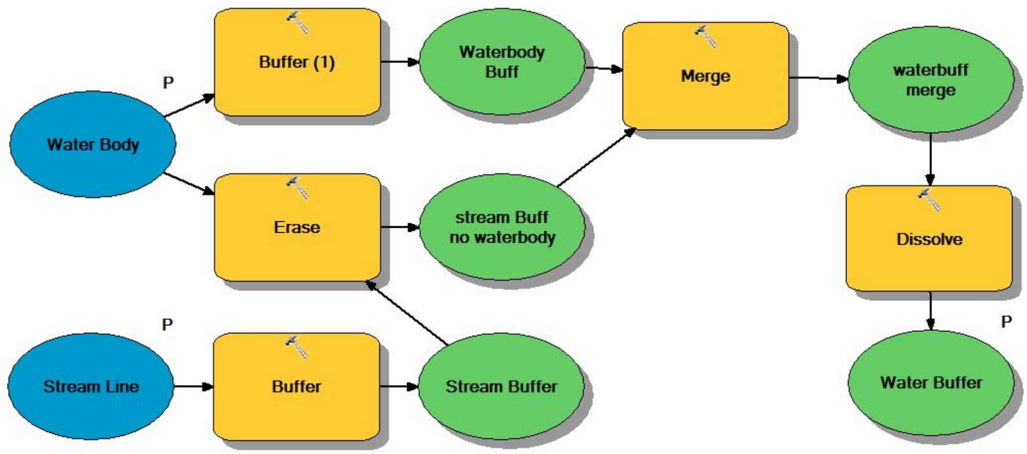


**Figure C4: Riparian filtration assessments require several steps, each of which may be important to analysts. We present these steps separately, starting with the first step. A) Conceptual model illustrating the data inputs (blue), geospatial tools (yellow) and outputs (green) created within the model that creates a new shapefile reflecting a 50-m (fixed distance) riparian zone bounding all surface waters. B) ArcTool interface where the user can browse to enter data inputs and define the location of the final output that maps the riparian zone described above.**

A)




B)

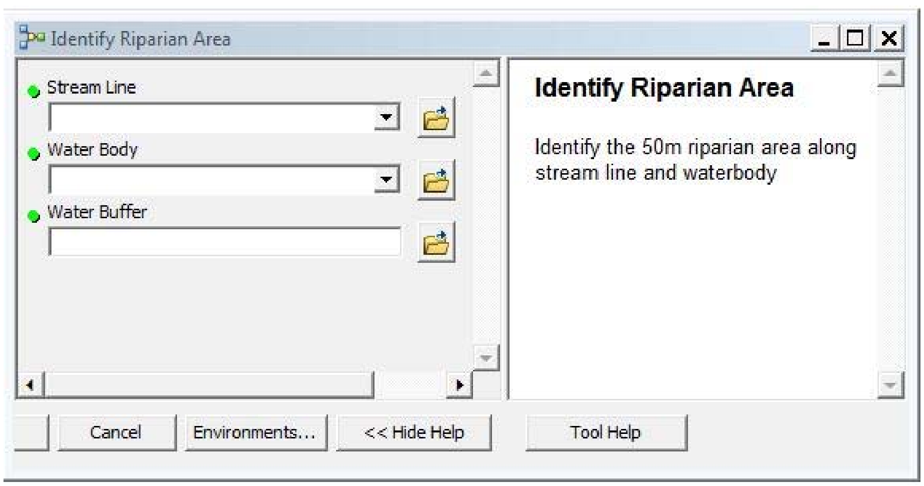
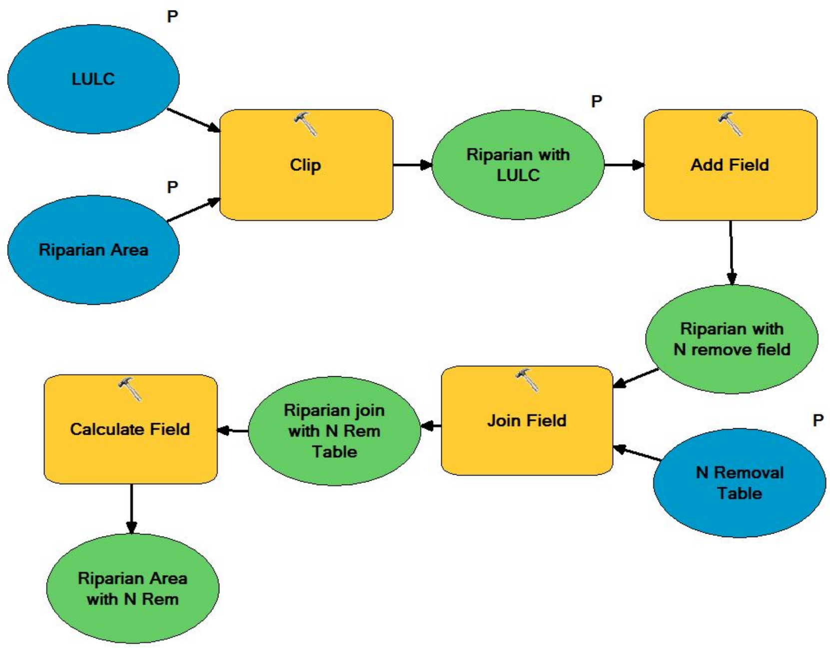


**Figure C5: Step two of the riparian filtration model incorporates land cover and expected filtration values. A) Conceptual model illustrating the data inputs (blue), geospatial tools (yellow) and outputs (green) created within the model that creates a new shapefile that provides estimated filtration values (%) based on land cover within a 50-m (fixed distance) riparian zone. B) ArcTool interface where the user can browse to enter data inputs and define the location of the final output that maps expected nitrogen filtration (%) from the50-m riparian zone bounding all surface waters.**

A)




B)

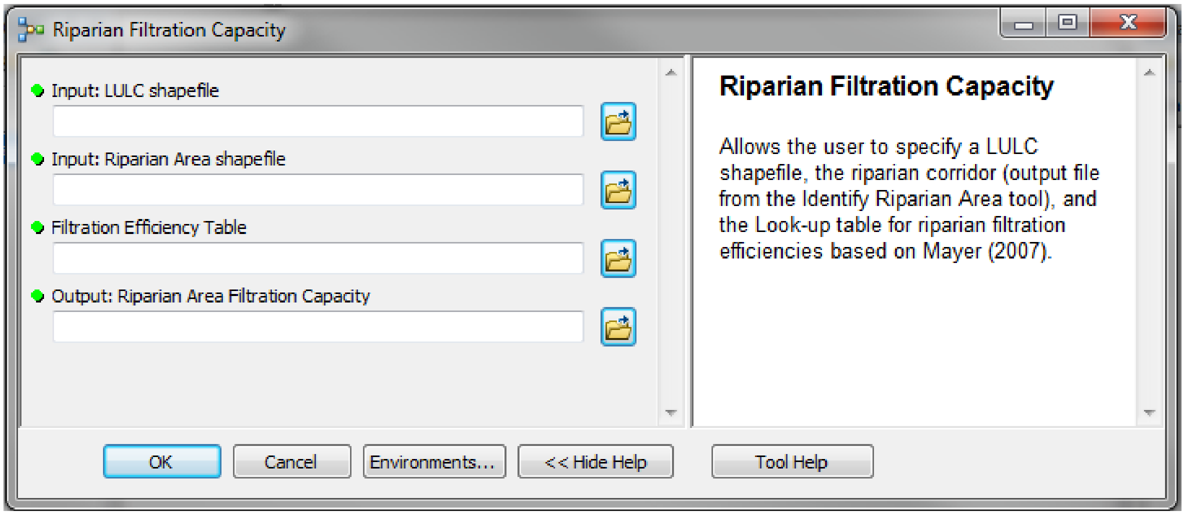
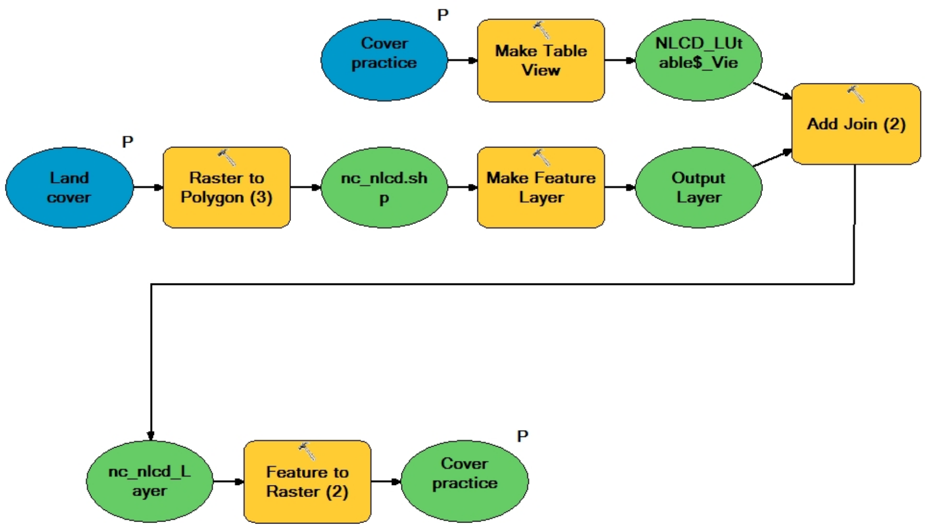


**Figure C6: The sediment retention model comprises five factors that require preprocessing. The first factor input is the cover practice (C) factor. A) Conceptual model illustrating the data inputs (blue), geospatial tools (yellow) and computational outputs (green) that create a new raster that assigns a C value to all pixels within the area defined by the land cover input raster. B) ArcTool interface where the user can browse to enter data inputs and define the location of the final output that assigns a C value to all pixels within the area defined by the land cover input.**

A)




B)

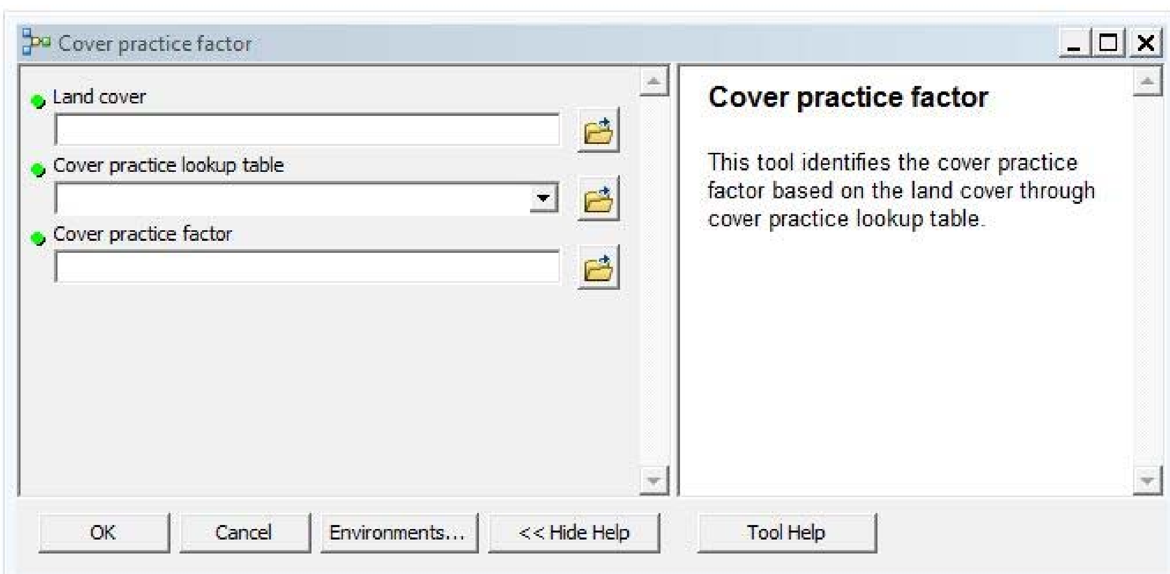
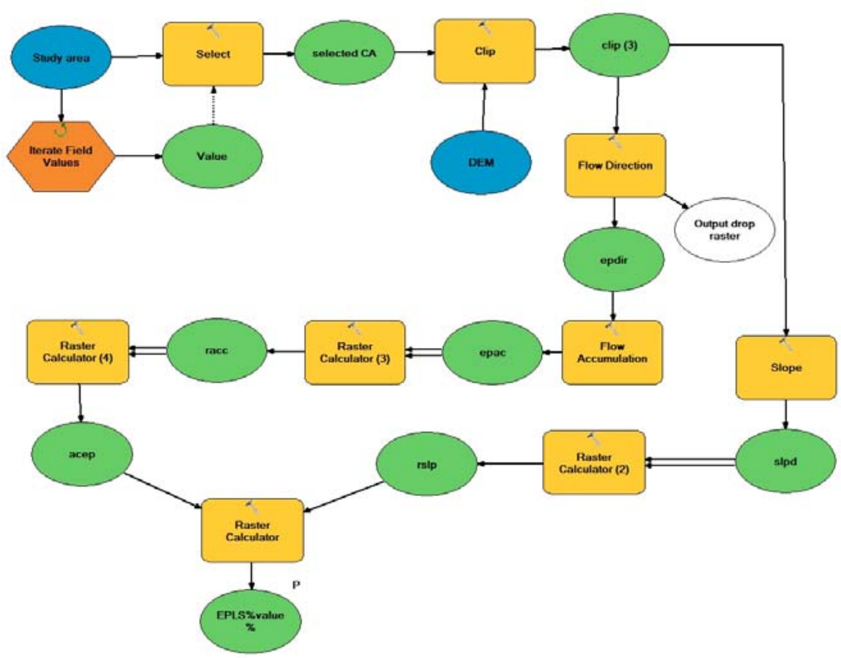


**Figure C7: The second and third sediment retention factors that requires preprocessing are combined as the slope-length (LS) factor. A) Conceptual model illustrating the iterative process by which the data inputs (blue), geospatial tools (yellow) and computational outputs (green) create a new raster that assigns a LS value to all pixels within the defined study areas (here, 12-digit hydrologic units). B) ArcTool interface where the user can browse to enter data inputs and define the location of the final output that assigns a LS value to all pixels within the predefined study area.**

A)




B)

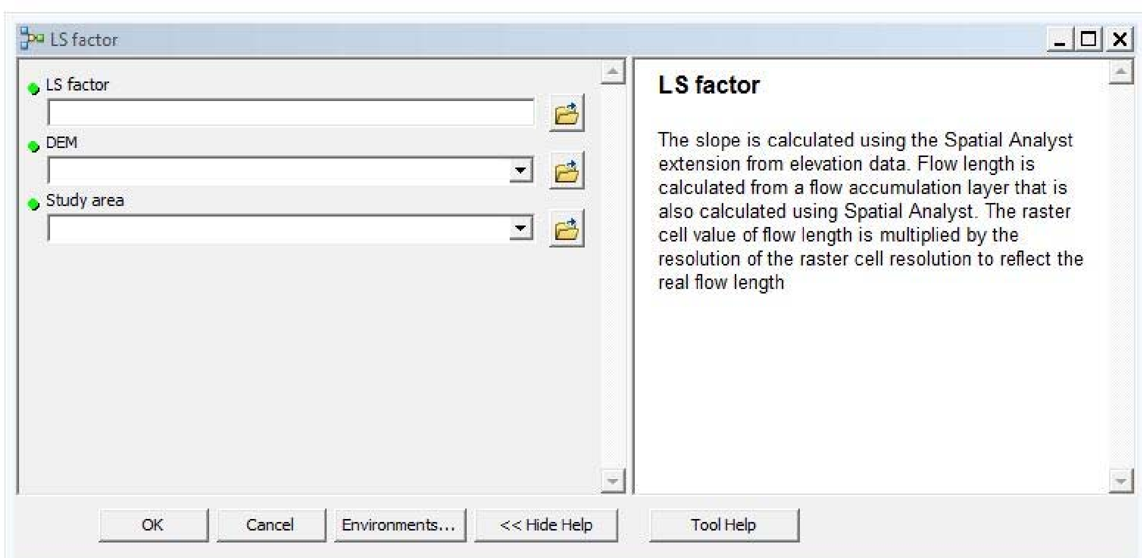
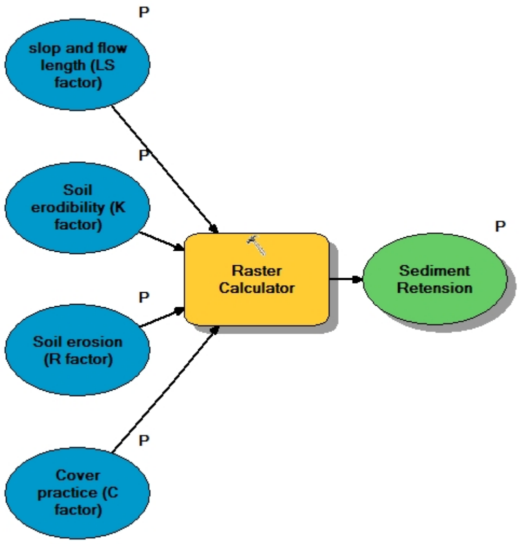


**Figure C8: The final two factors for the sediment retention model – soil erodibility (K) and soil erosion (R) – are simple data inputs provided to the installation and accessible at the national scale through the USDA-NRCS geospatial data gateway. A) Conceptual model illustrating the data inputs (blue), geospatial tools (yellow) and computational outputs (green) that create a new raster that assigns soil loss value (tons per acre) to all pixels within the area defined by the land cover input raster. B) ArcTool interface where the user can browse to enter data inputs and define the location of the final output that assigns a soil loss value (tons per acre) to all pixels within the area defined by the land cover input raster.**

A)




B)

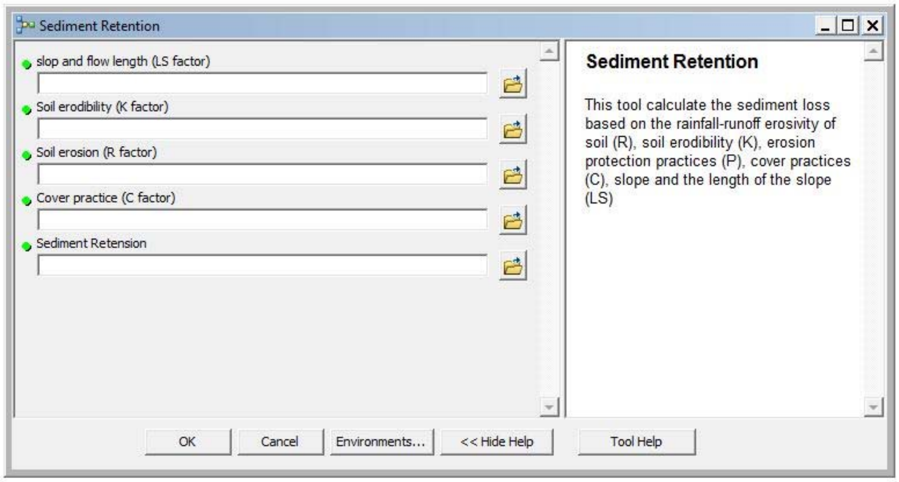
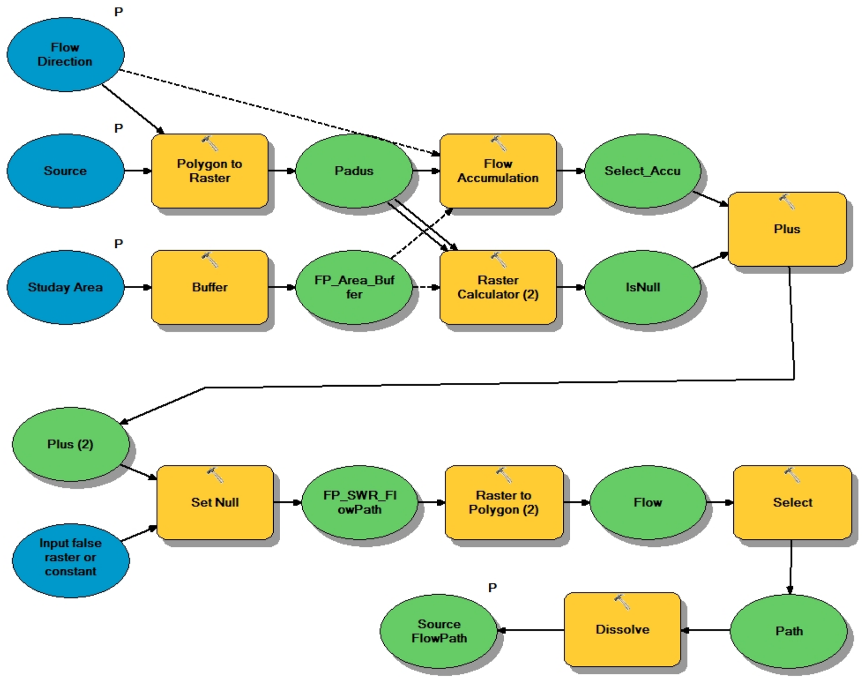
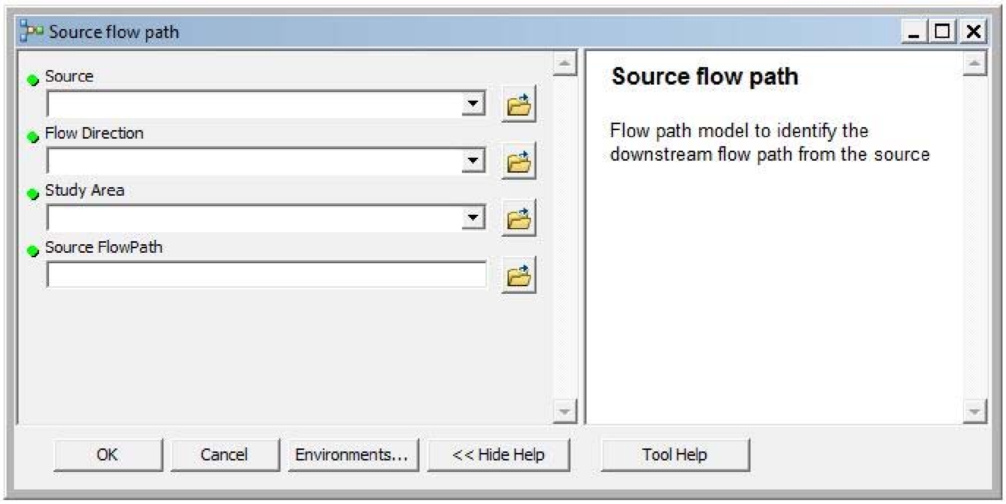


**Figure C9: To map the flow of ecological pressures and ecosystem service benefits we must first define areas that are considered "sources" (of services or disservices that exert ecological pressure). A) Conceptual model illustrating the data inputs (blue), geospatial tools (yellow) and computational outputs (green) that create a new shapefile of hydrologic flow paths from the source to a stream. B) ArcTool interface where the user can browse to enter data inputs and define the location of the final output that maps hydrologic flow paths from the source to a stream.**

A)




B)



## Appendix D: Land Cover - Land Use Accuracy Assessments

Below, we show confusion matrices of land cover – land use (LULC) that describe producer and user accuracy. Producer accuracy is defined as the probability that a certain land cover on the ground is accurately classified as such (usually from satellite imagery). User accuracy is the probability that a pixel labeled a certain LULC is actually that on the ground. Field data were collected during this demonstration on both installations to compare to data compiled from existing data sets maintained by Fort Pickett or Cherry Point. LULC codes follow the NLCD classification scheme. 11: open water, 21: open space, 22: low development, 23: medium development, 24: high development, 31: barren, 41: deciduous forest, 42: coniferous forest, 43: mixed forest, 52: shrubland, 71: grassland, 90: woody wetlands, 95: emergent wetlands. User accuracy tables (Tables D2 and D4) show the percentage of GIS pixels (compiled from existing data) that match observations on the ground. The far right column in user accuracy tables provide the number of sample points per LULC in the GIS database. The number of sample points per LULC was designed to represent the proportional coverage of those LULC on a given installation. In contrast, producer accuracy tables (Tables D1 and D3) show the probability that an observed ground-cover type was accurately classified in remotely sensed data. The bottom row in producer accuracy tables provide the number of sample points per LULC in the field. The user accuracy of a given LULC is highlighted in purple and should be interpreted as the probability that a GIS pixel labeled as a certain LULC is actually that on the ground. Likewise, the producer accuracy of a given LULC should be interpreted as the probability that a certain land cover on the ground was accurately classified as such in the compiled GIS data.

User accuracy for Fort Pickett was relatively high (> 50%) for the majority of sampled LULC. Producer accuracy for Fort Pickett was low, ranging from 0% to 75% for the 10 LULC sampled. User and producer accuracies for Cherry Point were extremely low; no LULC sampled from the databases matched LULC observed in the field.

**Table D1: Producer accuracy (i.e., certain land cover on the ground is accurately classified as such, usually from satellite imagery) expressed as a percentage (%) of GIS LULC data compiled from Fort Pickett. Numerical labels of columns and rows refer to specific LULC classes described in 2011 National Land Cover Dataset (Fry et al. 2011) and the values in the cross-tabulation indicate the percent of sites that were accurately classified by NLCD. Pixels (#) provides the total number of NLCD pixels ground-truthed.**

| | | Ground truth | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **11** | **21** | **22** | **23** | **24** | **31** | **41** | **42** | **43** | **52** | **71** | **80** | **81** | **90** | **95** |
| Classified in GIS data | **11** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **21** | 0 | **0** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **22** | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **23** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **24** | 0 | 0 | 0 | 0 | **0** | 100 | 50 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 |
| | **31** | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 8 | 0 | 0 | 0 | 8 | 0 | 0 | 0 |
| | **41** | 0 | 0 | 0 | 0 | 0 | 0 | **0** | 67 | 0 | 21 | 25 | 8 | 0 | 0 | 0 |
| | **42** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** | 67 | 21 | 0 | 0 | 0 | 0 | 0 |
| | **43** | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 8 | **22** | 33 | 0 | 0 | 0 | 0 | 0 |
| | **52** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | **0** | 0 | 0 | 0 | 0 | 0 |
| | **71** | 0 | 0 | 100 | 100 | 0 | 0 | 0 | 0 | 0 | 4 | **75** | 75 | 0 | 0 | 0 |
| | **80** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **81** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 8 | 0 | 0 | 0 |
| | **90** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | 0 | 13 | 0 | 0 | 0 | **0** | 100 |
| | **95** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **# ground truth pixels** | | **0** | **1** | **2** | **0** | **2** | **2** | **12** | **9** | **24** | **4** | **12** | **0** | **0** | **1** | **0** |

**Table D2: User accuracy (i.e., probability that a pixel labeled a certain LULC is actually that on the ground) expressed as a percentage (%) of GIS LULC data compiled from Fort Pickett. Numerical labels of columns and rows refer to specific LULC classes. Pixels (#) provides the total number of NLCD pixels ground-truthed.**

| Classified in GIS data | Ground truth | | | | | | | | | | | | | | | pixels (#) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **11** | **21** | **22** | **23** | **24** | **31** | **41** | **42** | **43** | **52** | **71** | **80** | **81** | **90** | **95** | |
| **11** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **21** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **22** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **23** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **24** | 0 | 0 | 0 | 0 | **50** | 25 | 0 | 0 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | **4** |
| **31** | 0 | 0 | 0 | 0 | 0 | **0** | 50 | 0 | 0 | 0 | 50 | 0 | 0 | 0 | 0 | **2** |
| **41** | 0 | 0 | 0 | 0 | 0 | 0 | **53** | 0 | 33 | 7 | 7 | 0 | 0 | 0 | 0 | **15** |
| **42** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **55** | 45 | 0 | 0 | 0 | 0 | 0 | 0 | **11** |
| **43** | 0 | 0 | 0 | 0 | 0 | 8 | 8 | 17 | **67** | 0 | 0 | 0 | 0 | 0 | 0 | **12** |
| **52** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | **1** |
| **71** | 0 | 6 | 13 | 0 | 0 | 0 | 0 | 0 | 6 | 19 | **56** | 0 | 0 | 0 | 0 | **16** |
| **80** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| **81** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 50 | 0 | **0** | 0 | 0 | **2** |
| **90** | 0 | 0 | 0 | 0 | 0 | 0 | 33 | 0 | 50 | 0 | 0 | 0 | 0 | **17** | 0 | **6** |
| **95** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |

**Table D3: Producer accuracy (i.e., certain land cover on the ground is accurately classified as such, usually from satellite imagery) expressed as a percentage (%) of GIS LULC data compiled from Cherry Point. Numerical labels of columns and rows refer to specific LULC classes described in 2011 National Land Cover Dataset (Fry et al. 2011) and the values in the cross-tabulation indicate the percent of sites that were accurately classified by NLCD. Pixels (#) provides the total number of NLCD pixels ground-truthed.**

| | | Ground truth | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 11 | 21 | 22 | 23 | 24 | 31 | 41 | 42 | 43 | 52 | 71 | 80 | 81 | 90 | 95 |
| Classified in GIS data | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 100 | 0 |
| | 21 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 22 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 24 | 0 | 67 | 0 | 0 | 0 | 0 | 0 | 40 | 0 | 13 | 0 | 0 | 0 | 0 | 0 |
| | 31 | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 41 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 |
| | 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** | 55 | 13 | 0 | 0 | 0 | 0 | 0 |
| | 43 | 0 | 33 | 0 | 0 | 0 | 0 | 100 | 0 | **0** | 25 | 0 | 0 | 0 | 0 | 0 |
| | 52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 0 |
| | 71 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 38 | **0** | 0 | 0 | 0 | 0 |
| | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 81 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 36 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| # ground truth pixels | | **0** | **0** | **3** | **0** | **0** | **2** | **0** | **1** | **5** | **11** | **8** | **0** | **0** | **0** | **2** |

**Table D4: User accuracy (i.e., probability that a pixel labeled a certain LULC is actually that on the ground) expressed as a percentage (%) of GIS LULC data compiled from Cherry Point. Numerical labels of columns and rows refer to specific LULC classes. Pixels (#) provides the total number of NLCD pixels ground-truthed.**

| | | Ground truth | | | | | | | | | | | | | | | # pixels |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 11 | 21 | 22 | 23 | 24 | 31 | 41 | 42 | 43 | 52 | 71 | 80 | 81 | 90 | 95 | |
| Classified in GIS data | 11 | **0** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33 | 0 | 0 | 0 | 0 | 67 | 0 | **3** |
| | 21 | 0 | **0** | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **2** |
| | 22 | 0 | 0 | **0** | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| | 23 | 0 | 0 | 0 | **0** | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| | 24 | 0 | 40 | 0 | 0 | **0** | 0 | 0 | 40 | 0 | 20 | 0 | 0 | 0 | 0 | 0 | **5** |
| | 31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | 41 | 0 | 0 | 0 | 0 | 0 | 0 | **0** | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | **1** |
| | 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** | 86 | 14 | 0 | 0 | 0 | 0 | 0 | **7** |
| | 43 | 0 | 25 | 0 | 0 | 0 | 0 | 25 | 0 | **0** | 50 | 0 | 0 | 0 | 0 | 0 | **4** |
| | 52 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | 71 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | **0** | 0 | 0 | 0 | 0 | **3** |
| | 80 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | 81 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| | 90 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 80 | 0 | 0 | 0 | 0 | **0** | 0 | **5** |
| | 95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |

## Appendix E: ESTCP Demonstration Assessment Survey 2014

Instructions: Please answer each question thoughtfully and honestly, based on your experience with our ESTCP demonstration project and your knowledge of how our analytical approach might inform land-use planning or environmental compliance at Cherry Point/Fort Pickett.

**As part of our ESTCP demonstration, we addressed the following tasks and outcomes. Please assess our performance of each as 1) *Inadequate* (performance failed to meet expectations), 2) *Adequate* (performance met expectations), or 3) *Good* (performance exceeded expectations).**

| | **Inadequate** | **Adequate** | **Good** |
|---|---|---|---|
| 1. Clarity and accuracy of conceptual models used in ecosystem service analyses. | | | |
| 2. Demonstrated analytical need to distinguish capacity versus flow of ecosystem services. | | | |
| 3. Included in the analysis important factors that influence ecosystem service delivery. | | | |
| 4. Estimated ecosystem service capacity, demand, and flow. | | | |
| 5. Analyzed future scenarios based on plausible changes in relevant biophysical parameters and/or changes in land use management (including encroachment management). | | | |
| 6. Engaged key Cherry Point/Fort Pickett stakeholders. | | | |
| 7. Demonstrated the utility of scenario analysis to land use planning or environmental compliance. | | | |
| 8. Illustrated the general utility of an ecosystem services framework in land use planning or environmental compliance by Cherry Point/Fort Pickett managers. | | | |
| 9. Provided a user-friendly analytical framework and GIS tools. | | | |
| 10. Provided end-user guidance for future use of GIS tools. | | | |
| 11. Provided opportunities to evaluate the demonstration team and project. | | | |

**For the next suite of questions, please check whether you *Strongly agree, Somewhat agree, Somewhat disagree, or Strongly disagree*.**

| | **Strongly agree** | **Somewhat agree** | **Somewhat disagree** | **Strongly disagree** |
|---|---|---|---|---|
| 12. Framing environmental issues in terms of ecosystem service delivery – with separate components of service capacity, ecological pressure and flow – can provide natural resource/environmental managers on military institutions with helpful information that can be used in decision-making regarding environmental issues. | | | | |
| 13. Analyzing water quality issues in terms of ecosystem service delivery – with separate components of the capacity, ecological pressure, and flow of water purification services – provides instructive information that can be used in conjunction with conventional analyses of ambient water quality. | | | | |
| 14. Analyzing water runoff (flooding/ponding) issues in terms of ecosystem service delivery – with separate components of the capacity, ecological pressure and flow of runoff regulation services – is more instructive than conventional analyses of land cover. | | | | |
| 15. Analyzing water quality issues in terms of ecosystem service delivery can help make land use planning or environmental compliance on and around Cherry Point/Fort Pickett more cost-effective. | | | | |
| 16. Maps help envision the relationships among RS capacity, ecological pressures, and the flow of services and disservices. | | | | |
| 17. Mapping the spatially-explicit capacity of an area to provide regulating services can inform decisions regarding land use. | | | | |
| 18. It was helpful for installation stakeholders to be involved in the scenario scoping process. | | | | |

**The next suite of questions refers to the time you had to invest in this ESTCP demonstration.**

| | **Less than expected** | **As expected** | **More than expected** |
|---|---|---|---|
| 19. The total amount of time required by you to participate in this project | | | |
| 20. Time spent in face-to-face meetings with team members | | | |
| 21. Time spent preparing and disseminating data to demo team members | | | |
| 22. Ease of communication with team leaders (Amy & Paul) | | | |

**Please check whether you are interested in participating in another ESTCP demonstration or SERDP research project.**

| | **Very interested** | **Maybe, it depends on topic** | **Not interested** |
|---|---|---|---|
| 23. An ESTCP demonstration (no new research, just application of existing methods or tools) | | | |
| 24. A SERDP research project (new research to develop new methods or results specific to base) | | | |

**Please offer any other comments regarding things you liked or disliked about our demonstration project. If you have ideas for future projects that you would like to pursue, please include them.**